SCIENTIFIC DIALOGUES.

INTENDED FOR THE

INSTRUCTION AND ENTERTAINMENT

OF

YOUNG PEOPLE:

IN WHICH

THE FIRST PRINCIPLES

OF

NATURAL AND EXPERIMENTAL PHILOSOPHY

ARE FULLY EXPLAINED.

VOL. I. OF MECHANICS AND ASTRONOMY.

"Conversation, with the habit of explaining the meaning of words and "the structure of common domestic implements to children, is the sure "and effectual method of preparing the mind for the acquirement of sci- "ence."—*Edgeworth's Practical Education.*

BY THE REV. J. JOYCE.

A NEW EDITION, CORRECTED AND IMPROVED.

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TO THE HONOURABLE

CHARLES BANKS STANHOPE,*

AND TO THE HONOURABLE

JAMES HAMILTON STANHOPE.

GENTLEMEN,

I AM desirous of prefixing your names to these volumes in token of the affectionate attachment to which, from me, you are peculiarly entitled. And I am happy in the opportunity which this publication affords me of bringing to your recollection subjects, in the study of which you successfully engaged at a very early period of life, and which are of acknowledged importance in the pursuits of every well-educated youth.

* This young man, the second son of the present Earl Stanhope, chose at an early period the profession of arms. In the year 1807, he was appointed aid-de-camp to general Moore, whom he accompanied to Sicily and Sweden. In the latter end of the year 1808, he was, as major, appointed to the command of the 50th regiment, then in Spain, at the head of which he was shot through the heart, at Corunna, on the 16th of January, 1809.

In perusing this little work you must bear in your minds, that it is not intended for proficients in philosophical knowledge, but for noviciates in science; not for yourselves in the present advanced stage of your progress, but for those young persons who are unacquainted with the rudiments of natural and experimental philosophy.

I am too well acquainted with the excellence of your dispositions to suppose it necessary for me to apologize for laying before you a work that has no extraordinary claim to your acceptance. You will, I am sure, appreciate its value, not so much by its intrinsic contents, as by the good-will with which it is presented.

Before I conclude this short address, permit me to say, that my own happiness will ever be much augmented, by the assurance of the happiness and distinguished usefulness of those with whom I have spent so many years of my life, and to whose permanent interest, I am sure, you will acknowledge I have never been inattentive.

Sincerely wishing you, Gentlemen, all the felicity which the honourable exercise of distinguished talents and virtuous minds can confer upon the possessors,

I subscribe myself

Your very affectionate Friend

And obedient Servant,

THE AUTHOR.

Clapton, May, 1800.

PREFACE

THE author of these little volumes feels himself extremely happy in the opportunity which this publication affords him of acknowledging the obligations he is under to the authors of "Practical Education," for the pleasure and instruction which he has derived from that valuable work. To this he is solely indebted for the idea of writing on the subject of Natural Philosophy for the use of children. How far his plan corresponds with that suggested by Mr. Edgeworth in his chapter on Mechanics, must be left with a candid public to decide.

The author conceives at least, he shall be justified in asserting, that no introduction to natural and experimental philosophy has been attempted in a method so familiar and easy as that which he now offers to the public:—none which appears to him so properly adapted to the capacities of young people of ten or eleven years of age, a period of life, which, from the author's own experience, he is confident, is by no means too early to induce in children habits of scientific reasoning. In this opinion he is sanctioned by the authority of Mr. Edgeworth. "Parents," says he, "are anxious that children should be conversant with mechanics, and with what are called the mechanical powers. Certainly no species of knowledge is better suited to the taste and capacity of youth, and yet it sel-

dom forms a part of early instruction. Every body talks of the lever, the wedge, and the pulley, but most people perceive that the notions which they have of their respective uses are unsatisfactory and indistinct, and many endeavour, at a late period of life, to acquire a scientific and exact knowledge of the effects that are produced by implements which are in every body's hands, or that are absolutely necessary in the daily occupations of mankind."

Should these volumes be favourably received by the public, the author proposes to pursue the same plan in four others, for which he has ample materials, and which will comprise Optics, Hydrostatics, Pneumatics, Chemistry, Electricity, and Magnetism.* He is aware that to persons conversant with these subjects, and who are accustomed to the arduous employment of education, hints for the improvement of this work may occur; so far, therefore, from deprecating candid criticism, whether of a public or private nature, he will thankfully attend to every liberal suggestion that may be offered; and will, in the revision of these volumes, or in writing those that remain to the completion of his design, avail himself of every advantage with which he may be favoured.

The author trusts that the whole work will be found a complete compendium of natural and experimental philosophy, not only adapted to the understandings of young people, but well calculated also to convey that kind of familiar instruction

* These volumes have been published, and have all been sanctioned by the decided public approbation, having passed through several large editions.

which is absolutely necessary, before a person can attend public lectures in these branches of science with advantage. "If," says Mr. Edgeworth, speaking on this subject, "the lecturer does not communicate much of that knowledge which he endeavours to explain, it is not to be attributed either to his want of skill, or to the insufficiency of his apparatus, but to the novelty of the terms which he is obliged to use. Ignorance of the language in which any science is taught, is an insuperable bar to its being suddenly acquired; besides a precise knowledge of the meaning of terms, we must have an instantaneous idea excited in our minds whenever they are repeated; and, as this can be acquired only by practice, it is impossible that philosophical lectures can be of much service to those who are not familiarly acquainted with the technical language in which they are delivered."*

It is presumed that an attentive perusal of these dialogues, in which the principal and most common terms of science are carefully explained and illustrated, by a variety of familiar examples, will be the means of obviating this objection, with respect to persons who may be desirous of attending those public philosophical lectures to which the inhabitants of the metropolis have almost constant access.

* Mr. Edgeworth's chapter on Mechanics should be recommended to the attention of the reader, but the author feels unwilling to refer to a part of a work, the whole of which deserves the careful perusal of all persons engaged in the education of youth.

CONVERSATION I.

INTRODUCTION.

FATHER—CHARLES—EMMA.

CHARLES. Father, you told sister Emma and me, that after we had finished the "*Evenings at Home*," you would explain to us some of the principles of natural philosophy: will you begin this morning?

Father. Yes, I am quite at leisure; and, I shall indeed at all times take a delight in communicating to you the elements of useful knowledge; and the more so in proportion to the desire which you have of collecting and storing those facts that may enable you to understand the operations of nature, as well as the works of ingenious artists. These, I trust, will lead you, insensibly, to admire the wisdom and goodness by means of which the whole system of the universe is constructed and supported.

Emma. But can philosophy be comprehended by children so young as we are? I thought that it had been the business of men, and of old men too.

Father. Philosophy is a word which in its original sense signifies only a love or desire of wisdom; and you will not allow that you and your brother are too young to wish for knowledge.

Emma. So far from it, that the more knowledge I get the better I seem to like it; and the number of new ideas which, with a little of your assistance, I have obtained from the "*Evenings at Home*," and the great pleasure which I have received from the perusal of these volumes, will, I am sure, excite me to read them again and again.

Father. You will find very little in the introductory parts of natural and experimental philosophy, that requires much more of your attention than many parts of that work with which you have been so delighted.

Charles. But in some books of natural philosophy, which I have occasionally looked into, a number of new and uncommon words have perplexed me; I have also seen references to figures by means of large letters and small, the use of which I did not comprehend.

Father. It is frequently a dangerous practice for young minds to dip into subjects before they are prepared, by some previous knowledge, to enter upon them; since it may create a distaste for the most interesting topics. Thus those books which you now read with so much pleasure would not have afforded you the smallest

entertainment a few years ago, when you must have spelt out almost every word in each page. The same sort of disgust will naturally be felt by persons who attempt to read works of science before the leading terms are explained and understood. The word *angle* is continually recurring in subjects of this sort, do you know what an angle is?

Emma. I do not think I do; will you explain what it means?

Father. An *angle* is made by the opening of two straight* lines. In this figure (Plate I. Fig. 1.) there are two straight lines AB and CB meeting at the point B, and the opening made by them is called an angle.

Charles. Whether that be small or great, is it still called an angle?

Father. It is; your drawing compasses may familiarize to your mind the idea of an angle; the lines in this figure will aptly represent the legs of the compasses, and the point B the joint upon which they move or turn. Now you may open the legs to any distance you please, even so far that they shall form one straight line; in that position only they do *not* form an angle. In every other situation an angle is made by the opening of these legs, and the angle is said to be greater or less, as that opening is greater or less.

* *Straight* lines, in works of science, are usually denominated *right* lines.

Emma. Are not some angles called right angles?

Father. Angles are either *right*, *acute*, or *obtuse*. When the line AB (Plate I. Fig. 2.) meets another line DC, in such a manner as to make the angles ABD and ABC equal to one another, then those angles are called *right* angles. And the line AB is said to be perpendicular to DC. Hence to be perpendicular to, or to make *right* angles with a line, means one and the same thing.

Charles. Does it signify how you call the letters of an angle?

Father. It is usual to call every angle by three letters, and that at the angular point must be always the middle letter of the three. There are cases, however, where an angle may be denominated by a single letter, as in figures 1 and 3, the angle ABC may be called simply the angle B, for in these figures there is no danger of mistake, because there is but a single angle at the point B.

Charles. I understand this, for if in the second figure I were to describe the angle by the letter B only, you would not know whether I meant the angle ABC or ABD.

Father. That is the precise reason why it is necessary in most descriptions to make use of three letters. An *acute* angle (Fig. 1.) ABC is less than a right angle; and an *obtuse* angle (Fig. 3.) ABC is greater than a right angle.

Emma. You see the reason now, Charles, why letters are placed against or by the figures, which puzzled you before.

Charles. I do: they are intended to distinguish the separate parts of each, in order to render the description of them easier both to the author and the reader.

Emma. What is the difference between an angle and a triangle?

Father. An angle being made by the opening of two lines, and, as you know, that two straight lines cannot enclose a space, so a *triangle* ABC (Fig. 4.) is a space bounded by three straight lines. It takes its name from the property of containing three angles. There are various sorts of triangles, but it is not necessary to enter upon these particulars, as I do not wish to burden your memories with more technical terms than we have occasion for.

Charles. A triangle then is a space or figure containing three angles, and bounded by as many straight lines.

Father. Yes, that description will answer our present purpose.

CONVERSATION II.

Of Matter.—Of the Divisibility of Matter.

Father. Do you understand what philosophers mean when they make use of the word matter?

Emma. Are not all things which we see and feel composed of matter?

Father. Every thing which is the object of our senses is composed of matter differently modified or arranged. But in a philosophical sense *matter* is defined to be *extended, solid, inactive*, and *moveable* substance.

Charles. If by extension is meant length, breadth, and thickness, matter, undoubtedly, is an extended substance. Its solidity is also manifest by the resistance it makes to the touch.

Emma. And the other properties nobody will deny, for all material objects are, of themselves, without motion: and yet it may be readily conceived, that by the application of a proper force there is no body which cannot be moved. But I remember, papa, that you told us something strange about the divisibility of matter, which you said might be continued without end.

Father. I did, some time ago, mention this as a curious and interesting subject, and this is a very fit time for me to explain it.

Charles. Can matter indeed be infinitely divided, for I suppose that this is what is meant by a division without end?

Father. Difficult as this may at first appear, yet I think it very capable of proof. Can you conceive of a particle of matter so small as not to have an upper and under surface?

Charles. Certainly, every portion of matter, however minute, must have two surfaces at least, and then I see, that it follows of course that it is divisible.

Father. Your conclusion is just, and though there may be particles of matter too small for us actually to divide, yet this arises from the imperfection of our instruments; they must nevertheless, in their nature, be divisible.

Emma. But you were to give us some remarkable instances of the minute division of matter.

Father. A few years ago a lady spun a single pound of wool into a thread 168,000 yards long. And Mr. Boyle mentions that two grains and a half of silk was spun into a thread 300 yards in length. If a pound of silver, which, you know, contains 5760 grains, and a single grain of gold be melted together, the gold will be equally diffused through the whole silver, insomuch that if one grain of the mass be dissolved in a liquid called *Aqua Fortis*, which is diluted nitric acid, the gold will fall to the bottom. By this experiment it is evident that a grain may be divided into 5761 visible parts, for only the 5761st part

of the gold is contained in a single grain of the mass.

The gold-beaters, whom you have seen at work in the shops in Long-Acre, can spread a grain of gold into a leaf containing fifty square inches, and this leaf may be readily divided into 500,000 parts, each of which is visible to the naked eye: and by the help of a microscope which magnifies the area or surface of the body 100 times, 100th part of each of these becomes visible, that is, the 50 millionth part of a grain of gold will be visible, or a single grain of that metal may be divided into fifty million of visible parts. But the gold which covers the silver wire used in making what is called gold lace, is spread over a much larger surface, yet it preserves, even if examined by a microscope, an uniform appearance. It has been calculated that one grain of gold under these circumstances would cover a surface of nearly thirty square yards.

The *natural* divisions of matter are still more surprising. In odoriferous bodies, such as camphor, musk, and asafœtida, a wonderful subtilty of parts is perceived, for though they are perpetually filling a considerable space with odoriferous particles, yet these bodies lose but a very small part of their weight in a great length of time.

Again, it is said by those who have examined the subject with the best glasses, and whose

accuracy may be relied on, that there are more animals in the milt of a single cod-fish, than there are men on the whole earth, and that a single grain of sand is larger than four millions of these animals. Now if it be admitted that these little animals are possessed of organized parts, such as a heart, stomach, muscles, veins, arteries, &c. and that they are possessed of a complete system of circulating fluids, similar to what is found in larger animals, we seem to approach to an idea of the infinite divisibility of matter. It has indeed been calculated that a particle of blood of one of these animalcula is as much smaller than a globe one-tenth of an inch in diameter, as that globe is smaller than the whole earth. Nevertheless, if these particles be compared with the particles of light, it is probable, that they would be found to exceed them in bulk as much as mountains do single grains of sand:

In thousand species of the insect kind!
Lost to the naked eye, so wondrous small
Were millions join'd, one grain of sand would cover all,
Yet each within its little bulk, contains
A heart which drives the torrent through its veins;
Muscles to move its limbs aright; a brain
And nerves disposed for pleasure and for pain;
Eyes to distinguish; sense whereby to know
What's good or bad; is, or is not its foe. BAKER.

I might enumerate many other instances of the same kind, but these, I doubt not, will be

sufficient to convince you into what very minute parts matter is capable of being divided: and with these we will put an end to our present conversation.

CONVERSATION III.

Of the Attraction of Cohesion.

Father. Well, my children, have you reflected upon what we last conversed about? Do you comprehend the several instances which I enumerated as examples of the minute division of matter?

Emma. Indeed the examples which you gave us very much excited my wonder and admiration, and yet from the thinness of some leaf-gold which I once had, I can readily credit all you have said on that part of the subject. But I know not how to conceive of such small animals as you described; and I am still more at a loss how to imagine that animals so minute, should possess all the properties of the larger ones, such as a heart, veins, blood, &c.

Father. I can, the next bright morning, by the

help of my solar microscope, show you very distinctly, the circulation of the blood in a flea, which you may get from your little dog; and with better glasses than those of which I am possessed, the same appearance might be seen in animals still smaller than the flea, perhaps, even in those which are themselves invisible to the naked eye. But we shall converse more at large on this matter, when we come to consider the subject of optics, and the construction and uses of the solar microscope. At present we will turn our thoughts to that principle in nature, which philosophers have agreed to call gravity or attraction.

Charles. If there be no more difficulties in philosophy than we met with in our last lecture, I do not fear but that we shall, in general, be able to understand it. Are there not, papa, several kinds of gravity?

Father. Yes, there are; two of which it will be sufficient for our present purpose to describe; the one is the *attraction of cohesion;* the other that of *gravitation.* The *attraction of cohesion* is that power which keeps the parts of bodies together when they touch, and prevents them from separating, or which inclines the parts of bodies to unite, when they are placed sufficiently near to each other.

Charles. Is it then by the attraction of cohesion that the parts of this table, or of the penknife, are kept together?

Father. The instances which you have selected are accurate, but you might have said the same of every other solid substance in the room, and it is in proportion to the different degrees of attraction with which different substances are affected, that some bodies are hard, others soft, tough, &c. A Philosopher in Holland, almost a century ago, took great pains in ascertaining the different degrees of cohesion, which belonged to various kinds of wood, metals, and many other substances. A short account of the experiments made by M. Musschenbroek, you will hereafter find in your own language, in the second edition of Dr. Enfield's Institutes of Natural Philosophy.

Charles. You once showed me that two leaden bullets having a little scraped from the surfaces would stick together with great force; you called that, I believe, the attraction of cohesion?

Father. I did: some philosophers who have made this experiment with great attention and accuracy, assert, that if the flat surfaces, which are presented to one another, be but a quarter of an inch in diameter, scraped very smooth, and forcibly pressed together with a twist, a weight of a hundred pounds is frequently required to separate them.

As it is by this kind of attraction that the parts of solid bodies are kept together, so when any substance is separated or broken, it is only

the attraction of cohesion, that is overcome in that particular part.

Emma. Then, papa, when I had the misfortune this morning at breakfast, to let my saucer slip from my hands, by which it was broken into several pieces, was it only the attraction of cohesion that was overcome by the parts of the saucer being separated by its fall on the ground?

Father. Just so; for whether you unluckily break the china, or cut a stick with your knife, or melt lead over the fire, as your brother sometimes does, in order to make plummets: these and a thousand other instances, which are continually occurring, are but examples in which the cohesion is overcome by the fall, the knife, or the fire.

Emma. The broken saucer being highly valued by mamma, she has taken the pains to join it again with white lead; was this performed by means of the attraction of cohesion?

Father. It was, my dear; and hence you will easily learn that many operations in cookery are in fact nothing more than different methods of causing this attraction to take place. Thus flour, by itself, has little, or nothing of this principle, but when mixed with milk, or other liquids, to a proper consistency, the parts cohere strongly, and this cohesion in many instances becomes still stronger, by means of the heat applied to it in boiling or baking.

Charles. You put me in mind, papa, of the fable of the man blowing hot and cold: for in the instance of the *lead*, fire overcomes the attraction of cohesion; and the same power, heat, when applied to puddings, bread, &c. causes their parts to cohere more powerfully. How are we to understand this?

Father. I will endeavour to remove your difficulty. Heat expands all bodies without exception, as you shall see before we have finished our lectures. Now the fire applied to metals in order to melt them, causes such an expansion, that the particles are thrown out of the sphere, or reach of each other's attraction: whereas the heat communicated in the operations of cookery, is sufficient to expand the particles of flour, but is not enough to overcome the attraction of cohesion. Besides, your mamma will tell you that the heat of boiling would frequently disunite the parts of which her puddings are composed, if she did not take the precaution of enclosing them in a cloth, leaving them just room enough to expand without the liberty of breaking to pieces; and the moment they are taken from the water, they lose their superabundant heat, and become solid.

Emma. When Ann the cook makes broth for little brother, it is the heat then which overcomes the attraction which the particles of meat have for each other, for I have seen her pour off

the broth, and the meat is all in rags. But will not the heat overcome the attraction which the parts of the bones have for each other?

Father. The heat of boiling water will never effect this, but a machine was invented several years ago, by Mr. Papin, for that purpose. It is called Papin's digester, and is used in taverns, and in many large families, for the purpose of dissolving bones, as completely as a lesser degree of heat will liquefy jelly. On some future day I will show you an engraving of this machine, and explain its different parts, which are extremely simple.*

CONVERSATION IV.

Of the Attraction of Cohesion.

Father. I will now mention some other instances of this great law of nature. If two polished plates of marble, or brass, be put together with a little oil between them to fill up the pores in their surfaces, they will cohere so powerfully as to require a very considerable force to separate them.—Two globules of quick-

* See Vol. II. Conver. XL.

silver placed very near to each other, will run together and form one large drop.—Drops of water will do the same.—Two circular pieces of cork placed upon water at about an inch distant will run together.—Balance a piece of smooth board on the end of a scale beam; then let it lie flat on water, and five or six times its own weight will be required to separate it from the water. If a small globule of quicksilver be laid on clean paper, and a piece of glass be brought into contact with it, the mercury will adhere to it, and be drawn away from the paper. But bring a larger globule into contact with the smaller one, and it will forsake the glass, and unite with the other quicksilver.

Charles. Did not you tell me that it was by means of the attraction of cohesion, that the little tea which is generally left at the bottom of the cup instantly ascends in the sugar when thrown into it?

Father. The ascent of water or other liquids in sugar, sponge, and all porous bodies, is a species of this attraction, and is called *capillary** *attraction;* it is thus denominated from the property which tubes of very small bore, scarcely larger than to admit a hair, have of causing water to stand above its level.

Charles. Is this property visible in no other tubes than those, the bores of which are so exceedingly fine?

* From *capillus*, the Latin word for *hair*.

Father. Yes, it is very apparent in tubes whose diameters are one-tenth of an inch or more in length, but the smaller the bore, the higher the fluid rises; for it ascends, in all instances, till the weight of the column of water in the tube balances, or is equal to the attraction of the tube. By immersing tubes of different bores in a vessel of coloured water, you will see that the water rises as much higher in the smaller tube, than in the larger, as its bore is less than that of the larger. The water will rise a quarter of an inch, and there remain suspended in a tube, whose bore is about one-eighth of an inch in diameter.

This kind of attraction is well illustrated, by taking (Plate I.. Fig. 5.) two pieces of glass joined together at the side BC, and kept a little open at the opposite side AD, by a small piece of cork E. In this position immerse them in a dish of coloured water, FG, and you will observe that the attraction of the glass at, and near BC, will cause the fluid to ascend to B, whereas about the parts D, it scarcely rises above the level of the water in the vessel.

Charles. I see that a curve is formed by the water.

Father. There is, and to this curve there are many curious properties belonging, as you will hereafter be able to investigate for yourself.

Emma. Is it not upon the principle of the

attraction of cohesion, that carpenters glue their work together?

Father. It is upon this principle that carpenters and cabinet makers make use of glue; that braziers, tinmen, plumbers, &c. solder their metals; and that smiths unite different bars of iron by means of heat. These and a thousand other operations, of which we are continually the witnesses, depend on the same principle as that which induced your mammá to use the white lead in mending her saucer. And you ought to be told, that though white lead is frequently used as a cement for broken china, glass, and earthen ware, yet if the vessels are to be brought again into use, it is not a proper cement, being an active poison; besides, one much stronger has been discovered, I believe, by a very able and ingenious philosopher, the late Dr. Ingenhouz, at least I had it from him several years ago; it consists simply of a mixture of quick-lime, and Gloucester cheese, rendered soft by warm water, and worked up to a proper consistency.

Emma. What! do such great philosophers, as I have heard you say Dr. Ingenhouz was, attend to such trifling things as these?

Father. He was a man deeply skilled in many branches of science; and I hope that you and your brother will one day make yourselves acquainted with many of his important discove-

ries. But no real philosopher will consider it beneath his attention to add to the conveniences of life.

Charles. This attraction of cohesion seems to pervade the whole of nature.

Father. It does, but you will not forget that it acts only at very small distances. Some bodies indeed appear to possess a power the reverse of the attraction of cohesion.

Emma. What is that, papa?

Father. It is called repulsion.

Thus water repels most bodies till they are wet. A small needle carefully placed on water will swim: flies walk upon it without wetting their feet:

> Or bathe unwet their oily forms, and dwell
> With feet repulsive on the dimpling well.
>
> DARWIN.

The drops of dew which appear in a morning on plants, particularly on cabbage plants, assume a globular form, from the mutual attraction between the particles of water; and upon examination it will be found that the drops do not touch the leaves, for they will roll off in compact bodies, which could not be the case if there subsisted any degree of attraction between the water and the leaf.

If a small thin piece of iron be laid upon quicksilver, the repulsion between the different metals will cause the surface of the quicksilver near the iron to be depressed.

The repelling force of the particles of a fluid is but small; therefore, if a fluid be divided, it easily unites again. But if a glass or any hard substance be broken, the parts cannot be made to cohere, without being first moistened, because the repulsion is too great to admit of a reunion.

The repelling force between water and oil is likewise so great, that it is impossible to mix them in such a manner, that they shall not separate again.

If a ball of light wood be dipped in oil, and then put into water, the water will recede so as to form a small channel around the ball.

Charles. Why do cane, steel, and many other things bear to be bent without breaking, and when set at liberty again, recover their original form?

Father. That a piece of thin steel, or cane, recovers its usual form after being bent, is owing to a certain power called *elasticity;* which may, perhaps, arise from the particles of those bodies, though disturbed, not being drawn out of each other's attraction; therefore, as soon as the force upon them ceases to act, they restore themselves to their former position.—But our half hour is expired, I must leave you.

CONVERSATION V.

Of the Attraction of Gravitation.

Father. We will now proceed to discuss another very important general principle in nature; the *attraction of gravitation*, or, as it is frequently termed, gravity, which is that power by which *distant* bodies tend towards each other. Of this we have perpetual instances in the falling of bodies to the earth.

Charles. Am I then to understand, that whether this marble falls from my hand; or a loose brick from the top of a house; or an apple from the tree in the orchard, that all these happen by the attraction of gravity?

Father. It is by the power which is commonly expressed under the term *gravity*, that all bodies whatever have a tendency to the earth, and, unless supported, will fall in lines nearly perpendicular to its surface.

Emma. But are not smoke, steam, and other light bodies which we see ascend, exceptions to the general rule?

Father. It appears so at first sight, and it was formerly received as a general opinion, that smoke, steam, &c. possessed no weight: the discovery of the air-pump has shown the

fallacy of this notion; for in an exhausted receiver, that is, in a glass jar from which the air is taken away by means of the air-pump, smoke and steam descend by their own weight as completely as a piece of lead. When we come to converse on the subject of pneumatics and hydrostatics, you will understand that the reason why smoke and other bodies ascend, is simply because they are lighter than the atmosphere which surrounds them, and the moment they reach that part of it which has the same gravity with themselves, they cease to rise.

Charles. Is it then by this power that all terrestrial bodies remain firm on the earth?

Father. By gravity, bodies on all parts of the earth (which you know is of a globular form) are kept on its surface, because they all, wherever situated, tend to the centre; and, since all have a tendency to the centre, the inhabitants of New Zealand, although nearly opposite to our feet, stand as firm as we do in Great Britain.

Charles. This is difficult to comprehend; nevertheless, if bodies on all parts of the surface of the earth have a tendency to the centre, there seems no reason why bodies should not stand firm on one part as well as another. Does this power of gravity act alike on all bodies?

Father. It does, without any regard to their figure, or size; for attraction or gravity acts upon bodies in proportion to the quantity of

matter which they contain, that is, four times a greater force of gravity is exerted on a weight of four pounds, than upon one of a single pound. The consequence of this principle is, that all bodies at equal distances from the earth fall with equal velocity.

Emma. What do you mean, papa, by *velocity?*

Father. I will explain it by an example or two; if you and Charles set out together, and *you* walk a mile in half an hour, but *he* walk and run two miles in the same time, how much swifter will he go than you?

Emma. Twice as swift.

Father. He does, because, *in the same time*, he passes over twice as much space; therefore we say his velocity was twice as great as yours. Suppose a ball, fired from a cannon, pass through 800 feet in a second of time; and in the same time your brother's arrow pass through 100 feet only, how much swifter does the cannon ball fly than the arrow?

Emma. Eight times swifter.

Father. Then it has eight times the velocity of the arrow; and hence you understand that swiftness and velocity are synonymous terms; and that the velocity of a body is measured by the space it passes over in a given time, as a second, a minute, an hour, &c.

Emma. If I let a piece of metal, as a penny piece, and a feather fall from my hand at the

same time, the penny will reach the ground much sooner than the feather. Now how do you account for this if all bodies are equally affected by gravitation, and descend with equal velocities, when at the same distance from the earth?

Father. Though the penny and feather will not, in the open air, fall with equal velocity, yet if the air be taken away, which is easily done, by a little apparatus connected with the air-pump, they will descend in the same time. Therefore the true reason why light and heavy bodies do not fall with equal velocities, is, that the *former*, in proportion to its weight, meets with a much greater resistance from the air than the *latter*.

Charles. It is then, I imagine, from the same cause, that if I drop the penny and a piece of light wood into a vessel of water, the penny shall reach the bottom, but the wood, after descending a small way, rises to the surface.

Father. In this case the resisting medium is water instead of air, and the copper being about nine times heavier than its bulk of water, falls to the bottom without apparent resistance. But the wood, being much lighter than water, cannot sink in it, therefore, though by its *momentum*,* it sinks a small distance, yet as soon

* The explanation of this term will be found in the next Conversation.

as that is overcome by the resisting medium, it rises to the surface, being the lighter substance.

CONVERSATION VI.

Of the Attraction of Gravitation.

Emma. The term *momentum* which you made use of yesterday, is another word which I do not understand.

Father. If you have understood what I have said respecting the velocity of moving bodies, you will easily comprehend what is meant by the word momentum.

The *momentum*, or moving force of a body, is its weight multiplied into its velocity. You may, for instance, place this pound weight upon a china plate without any danger of breaking, but if you let it fall from the height of only a few inches, it will dash the china to pieces. In the first case, the plate has only the pound weight to sustain, in the other, the weight must be multiplied into the velocity, or, to speak in a popular manner, into the distance of the height from which it fell.

If a ball *a* (Plate I. Fig. 6.) lean against the obstacle *b*, it will not be able to overturn it, but if it be taken up to *c* and suffered to roll down the inclined plane AB against *b*, it will certainly overthrow it;—in the former case, *b* would only have to resist the weight of the ball *a*, in the latter it has to resist the weight multiplied into its motion or velocity.

Charles. Then the momentum of a small body whose velocity is very great, may be equal to that of a very large body with a slow velocity.

Father. It may, and hence you see the reason why immense battering rams, used by the ancients, in the art of war, have given place to cannon balls of but a few pounds weight.

Charles. I do: for what is wanting in weight, is made up by velocity.

Father. Can you tell me what velocity a cannon ball of 28 pounds must have to effect the same purposes, as would be produced by a battering ram of 15,000 pounds weight, and which, by manual strength, could be moved at the rate of only two feet in a second of time?

Charles. I think I can;—the *momentum* of the battering ram must be estimated by its weight, multiplied into the space passed over in a second, which is 15,000 multiplied by two feet, equal to 30,000; now if this momentum, which must also be that of the cannon ball, be divided by the weight of the ball, it will give the velocity required; and 30,000 divided by 28, will

give for the quotient 1072 nearly, which is the number of feet which the cannon ball must pass over in a second of time, in order that the momenta of the battering ram and the ball may be equal, or in other words, that they may have the same effect in beating down an enemy's wall.

Emma. I now fully comprehend what the momentum of a body is, for if I let a common trap-ball accidentally fall from my hand, upon my foot, it occasions more pain than the pressure of a weight several times heavier.

Charles. If the attraction of gravitation be a power by which bodies in general tend towards each other, why do all bodies tend to the earth as a centre?

Father. I have already told you that by the great law of gravitation, the attraction of all bodies is in proportion to the quantity of matter which they contain. Now the earth, being so immensely large in comparison of all other substances in its vicinity, destroys the effect of this attraction between smaller bodies, by bringing them all to itself.—If two balls are let fall from a high tower at a small distance apart; though they have an attraction for one another, yet it will be as nothing when compared with the attraction by which they are both impelled to the earth, and consequently the tendency which they mutually have of approaching one another will not be perceived in the fall. If, however, any two bodies were placed in free space, and

out of the sphere of the earth's attraction, they would, in that case, assuredly fall towards each other, and that with increased velocity as they came nearer. If the bodies were equal, they would meet in the middle point between the two; but if they were unequal, they would then meet as much nearer the larger one, as that contained a greater quantity of matter than the other.

Charles. According to this, the earth ought to move towards falling bodies, as well as they move to it.

Father. It ought, and, in just theory, it does; but when you calculate how many million of times larger the earth is than any thing belonging to it, and if you reckon at the same time, the small distances from which bodies can fall, you will know that the point where the falling bodies and earth will meet, is removed only to an indefinitely small distance from its surface, a distance much too small to be conceived by the human imagination.

We will resume the subject of gravity to-morrow.

CONVERSATION VII.

Of the Attraction of Gravitation.

Emma. Has the attraction of gravitation, papa, the same effect on all bodies, whatever be their distance from the earth.

Father. No; this, like every power which proceeds from a centre, decreases as the squares of the distances from that centre increase.

Emma. I fear that I shall not understand this, unless you illustrate it by examples.

Father. Suppose you are reading at the distance of one foot from a candle, and that you receive a certain quantity of light on your book; now if you remove to the distance of two feet from the candle, you will, by this law, receive four times less light than you had before; here then, though you have increased your distance but two-fold, yet the light is diminished four-fold, because four is the square of two, or two multiplied by itself. If, instead of removing two feet from the candle, you take your station at 3, 4, 5, or 6 feet distance, you will then receive at the different distances, 9, 16, 25, 36 times less light than when you were within a single

foot from the candle, for these, as you know, are the squares of the numbers, 3, 4, 5, and 6. The same is applicable to the heat imparted by a fire; at the distance of one yard from which, a person will enjoy four times as much heat, as he who sits or stands two yards from it; and nine times as much as one that shall be removed to the distance of three yards.

Charles. Is then the attraction of gravity four times less at a yard distance from the earth, than it is at the surface?

Father. No; whatever be the cause of attraction, which to this day remains undiscovered, it acts from the *centre* of the earth, and not from its surface, and hence the difference of the power of gravity cannot be discerned at the small distances to which we can have access; for a mile or two, which is much higher than, in general, we have opportunities of making experiments, is nothing in comparison of 4000 miles, the distance of the centre from the surface of the earth. But could we ascend 4000 miles above the earth, and of course be double the distance that we now are from the centre, we should there find that the attractive force would be but one-fourth of what it is here; or in other words, that a body, which, at the surface of the earth, weighs one pound, and, by the force of gravity, falls through sixteen feet in a second of time, would at 4000 miles above the earth weigh but a

quarter of a pound, and fall through only four feet in a second.*

Emma. How is that known, papa, for nobody ever was there?

Father. You are right, my dear, for Garnerin, who last summer astonished all the people of the metropolis and its neighbourhood, by his flight in a balloon, ascended but a little way in comparison of the distance that we are speaking of. However, I will try to explain in what manner philosophers have come by their knowledge on this subject.

The moon is a heavy body, connected with the earth by this bond of attraction, and by the most accurate observations, it is known to be obedient to the same laws as other heavy bodies are: its distance is also clearly ascertained, being about 240,000 miles, or equal to about sixty semi-diameters of the earth, and of course the earth's attraction upon the moon ought to diminish in the proportion of the square of this distance, that is, it ought to be 60 times 60, or

* Ex. Suppose it were required to find the weight of a leaden ball, at the top of a mountain three miles high, which on the surface of the earth weighs 20lb.

If the semi-diameter of the earth be taken at 4000; then add to this the height of the mountain, and say as the square of 4003 is to the square of 4000, so is 20lb. to a fourth proportional: or as 16024009 : 16000000 : : 20 : 19.97 or something more than 19lb. 15½ oz. which is the weight of the leaden ball at the top of the mountain.

3600 times less at the moon than it is at the surface of the earth. This is found to be the case.

Again, the earth is not a perfect sphere, but a spheroid, that is, of the shape of an orange, rather flat at the two ends called the poles, and the distance from the centre to the poles is about eighteen or nineteen miles less than its distance from the centre to the equator, consequently, bodies ought to be something heavier at, and near the poles, than they are at the equator, which is also found to be the case. Hence it is inferred that the attraction of gravitation varies at all distances from the centre of the earth, in proportion as the squares of those distances increase.*

Charles. It seems very surprising that philosophers, who have discovered so many things, have not been able to find out the cause of gravity. Had Sir Isaac Newton been asked why a marble, dropped from the hand, falls to the ground, could he not have assigned a reason?

Father. That great man, probably the greatest man that ever adorned this world, was as modest as he was great, and he would have told you he knew not the cause.

The excellent and learned Dr. Price, in a work which he published twenty-five years ago, asks, "who does not remember a time when he

*See Vol. I. Conver. XXVII.

would have wondered at the question, *why does water run down hill?* What ignorant man is there who is not persuaded that he understands this perfectly? But every *improved* man knows it to be a question he cannot answer." For the descent of water, like that of other heavy bodies, depends upon the attraction of gravitation, the cause of which is still involved in darkness.

Emma. You just now said that heavy bodies by the force of gravity fall sixteen feet in a second of time, is that always the case?

Father. Yes, all bodies near the surface of the earth fall at that rate in the first second of time, but as the attraction of gravitation is continually acting, so the velocity of falling bodies is an increasing, or, as it is usually called, an *accelerating* velocity. It is found by very accurate experiments, that a body, descending from a considerable height by the force of gravity, falls 16 feet in the first second of time; 3 times 16 feet in the next; 5 times 16 feet in the third; 7 times 16 feet in the fourth second of time; and so on, continually increasing according to the odd numbers, 1, 3, 5, 7, 9, 11, &c.

CONVERSATION VIII.

Of the Attraction of Gravitation.

Emma. And would a ball of twenty pounds weight here, weigh half an ounce less on the top of the mountain?

Father. Certainly: but you would not be able to ascertain it by means of a pair of scales, and another weight, because both weights being in similar situations would lose equal portions of their gravity.

Emma. How, then, would you make the experiment?

Father. By means of one of those steel spiral-spring instruments, which you have seen occasionally used, the fact might be ascertained.

Charles. I think, from what you told us yesterday, that with the assistance of your stop-watch, I could tell the height of any place, by observing the number of seconds, that a marble or other heavy body would take in falling from that height.

Father. How would you perform the calculation?

Charles. I should go through the multiplications according to the number of seconds, and then add them together.

Father. Explain yourself more particularly: supposing you were to let a marble or penny-piece fall down that deep well which we saw last summer in the brick field near Ramsgate, and that it was exactly five seconds in the descent, what would be the depth of the well?

Charles. In the first second it would fall 16 feet; in the next 3 times 16 or 48 feet; in the third 5 times 16 or 80 feet; in the fourth 7 times 16 or 112 feet; and in the fifth second 9 times 16 or 144 feet; now if I add 16, 48, 80, 112, and 144 together, the sum will be 400 feet, which, according to your rule, is the depth of the well. But was the well so deep?

Father. I do not think it was, but we did not make the experiment; should we ever go to that place again, you may satisfy your curiosity. You recollect that at Dover Castle we were told of a well there 360 feet deep.

Though your calculation was accurate, yet it was not done as nature effects her operations, it was not performed in the shortest way.

Charles. I should be pleased to know an easier method; this, however, is very simple, it required nothing but multiplication and addition.

Father. True, but suppose I had given you an example in which the number of seconds had been fifty instead of five, the work would have taken you an hour or more to have performed it: whereas, by the rule which I am going to give, it might have been done in half a minute.

Charles. Pray let me have it, papa, I hope it will be easily remembered.

Father. It will; I think it cannot be forgotten after it is once understood. The rule is this, "*the spaces described by a body falling freely from a state of rest, increase as the* SQUARES *of the times increase.*" Consequently you have only to square the number of seconds, that is, you know, to multiply the number into itself; and then multiply that again by sixteen feet, the space which it describes in the first second, and you have the required answer. Now try the example of the *well.*

Charles. The square of 5, for the time, is 25, which multiplied by 16 gives 400 just as I brought it out before. Now if the seconds had been 50, the answer would be 50 times 50, which is 2500, and this multiplied by 16, gives 40,000 for the space required.

Father. I will now ask your sister a question, to try how she has understood this subject. Suppose you observe by this watch that the time of the flight of your brother's arrow is exactly six seconds, to what height does it arise?

Emma. This is a different question, because here the *ascent* as well as the *fall* of the arrow is to be considered.

Father. But you will remember, that the time of the ascent is always equal to that of the descent; for as the velocity of the descent is generated by the force of gravity, so is

the velocity of the ascent destroyed by the same force.

Emma. Then the arrow was three seconds only in falling; now the square of 3 is 9, which multiplied by 16, for the number of feet described in the first second, is equal to 144 feet, the height to which it rose.

Father. Now, Charles, if I get you a bow which will carry an arrow so high as to be fourteen seconds in its flight, can you tell me the height to which it ascends?

Charles. I can now answer you without hesitation:—it will be 7 seconds in falling, the square of which is 49, and this again multiplied by 16 will give 784 feet, or rather more than 261 yards for the answer.

Father. If you will now consider the example which you did the long way, you will see that the rule which I have given you answers very completely. In the first second the body fell 16 feet, and in the next 48, these added together make 64, which is the square of the 2 seconds multiplied by 16. The same holds true of the 3 first seconds, for in the third second it fell 80 feet, which added to the 64, give 144 equal to the square of 3 multiplied by 16. Again, in the fourth second it fell 112 feet, which added to 144, gives 256 equal to the square of 4 multiplied by 16: and in the fifth second it fell 144 feet, which added to 256, give 400 equal to the square of 5 multiplied by 16. Thus you will

find, the rule holds in all cases, *that the spaces described by bodies falling freely from a state of rest, increase as the* SQUARES *of the times increase.*

Charles. I think I shall not forget the rule. I will also show my cousin Henry how he may know the height to which his bow will carry.

Father. The surest way of keeping what knowledge we have obtained, is by communicating it to our friends.

Charles. It is a very pleasant circumstance, indeed, that the giving away is the best method of keeping, for I am sure, the being able to oblige one's friends is a most delightful thing.

Father. I have but a word or two more upon the subject: since the *whole spaces* described increase as the squares of the times increase, so also the *velocities* of falling bodies increase in the same proportion; for you know that the velocity must be measured by the space passed through. Thus if a person travels six miles an hour, and another person travels twelve miles in the same time, the latter will go with double the velocity of the former: consequently the *velocities* of falling bodies increase as the squares of the times increase.

If now you compare the spaces described by falling bodies in the *several moments of time taken separately*, and in their order from the beginning of the fall, then they, and consequently their velocities also, are to one another as the

odd numbers, 1, 3, 5, 7, 9, 11, 13, &c. taken in their natural order, as you will observe by reflecting on the foregoing examples.

With this we conclude our present conversation.

CONVERSATION IX.

Of the Centre of Gravity.

Father. We are now going to treat upon the *Centre of Gravity*, which is that point of a body in which its whole weight is as it were concentrated, and upon which if the body be freely suspended it will rest; and in all other positions it will endeavour to descend to the lowest place to which it can get.

Charles. All bodies then, of whatever shape, have a centre of gravity?

Father. They have: and if you conceive a line drawn from the centre of gravity of a body towards the centre of the earth, that line is called the *line of direction*, along which every body, not supported, endeavours to fall. If the *line of direction* fall within the base of any body,

it will stand; but if it does not fall within the base, the body will fall.

If I place the piece of wood A (Plate I. Fig. 7.) on the edge of a table, and from a pin *a* at its centre of gravity be hung a little weight *b*, the line of direction *ab* falls within the base, and therefore, though the wood leans, yet it stands secure. But if upon A, another piece of wood B be placed, it is evident that the centre of gravity of the whole will be now raised to *c*, at which point if a weight be hung, it will be found that the line of direction falls out of the base, and therefore the body must fall.

Emma. I think I now see the reason of the advice which you gave me, when we were going across the Thames in a boat.

Father. I told you that if ever you were overtaken by a storm, or by a squall of wind while you were on the water, never to let your fears so get the better of you, as to make you rise from your seat, because by so doing you would elevate the centre of gravity, and thereby, as is evident by the last experiment, increase the danger: whereas, if all the persons in the vessel were, at the moment of danger, instantly to slip from their places on to the bottom, the risk would be exceedingly diminished, by bringing the centre of gravity much lower within the vessel. The same principle is applicable to those who may be in danger of being overturned in any carriage whatever.

Emma. Surely then, papa, those stages which load their tops with a dozen or more people, cannot be safe for the passengers.

Father. They are very unsafe, but they would be more so, were not the roads about the metropolis remarkably even and good: and, in general, it is only within twenty or thirty miles of London, or other great towns, that the tops of carriages are loaded to excess.

Charles. I understand then, that the nearer the centre of gravity is to the base of a body, the firmer it will stand.

Father. Certainly; and hence you learn the reason why conical bodies stand so sure on their bases, for the tops being small in comparison of the lower parts, the centre of gravity is thrown very low: and if the cone be upright or perpendicular, the line of direction falls in the middle of the base, which is another fundamental property of steadiness in bodies. For the broader the base, and the nearer the line of direction is to the middle of it, the more firmly does a body stand: but if the line of direction fall near the edge, the body is easily overthrown.

Charles. Is that the reason why a ball is so easily rolled along a horizontal plane?

Father. It is; for in all spherical bodies, the base is but a point, consequently almost the smallest force is sufficient to remove the line of direction out of it. Hence it is evident, that heavy bodies situated on an inclined plane will,

while the line of direction falls within the base, slide down upon the plane: but they will roll when that line falls without the base. The body A (Plate I. Fig. 8.) will slide down the plane DE, but the bodies B and C will roll down it.

Emma. I have seen buildings lean very much out of a straight line, why do they not fall?

Father. It does not follow, because a building leans, that the eentre of gravity does not fall within the base. There is a high tower at Pisa, a town in Italy, which leans fifteen feet out of the perpendicular; strangers tremble to pass by it, still it is found by experiment that the line of direction falls within the base, and therefore it will stand while its materials hold together.

A wall at Bridgenorth, in Shropshire, which I have seen, stands in a similar situation, for so long as a line *cb* (Pate II. Fig. 9.) let fall from the centre of gravity *c* of the building AB, passes within the base CB, it will remain firm, unless the materials with which it is built go to decay.

Charles. It must be of great use in many cases to know the method of finding the centre of gravity in different kinds of bodies.

Father. There are many easy rules for this with respect to all manageable bodies; I will mention one, which depends on the property which the centre of gravity has, of always endeavouring to descend to the lowest point.

If a body A (Plate II. Fig. 10.) be freely sus-

pended on a pin *a*, and a plumb line *a* B be hung by the same pin, it will pass through the centre of gravity, for that centre is not in the lowest point, till it fall in the same line as the plumb line. Mark the line *a* B; then hang the body up by any other point, as D, with the plumb line DE, which will also pass through the centre of gravity for the same reason as before; and therefore as the centre of gravity is somewhere in *a* B, and also in some point of DE, it must be in the point c where those lines cross.

CONVERSATION X.

Of the Centre of Gravity.

Charles. How do those people who have to load carts and wagons with light goods, as hay, wool, &c., know where to find the centre of gravity?

Father. Perhaps the generality of them never heard of such a principle; and it seems surprising that they should nevertheless make up their loads with such accuracy as to keep the line of direction in or near the middle of the base.

Emma. I have sometimes trembled to pass by the hop-wagons which we have met on the Kent road.

Father. And without any impeachment of your courage, for they are loaded to such an enormous height, that they totter every inch of the road. It would indeed be impossible for one of these to pass with tolerable security along a road much inclined; the centre of gravity being removed so high above the body of the carriage, a small declination on one side or other would throw the line of direction out of the base.

Emma. When brother James falls about, is it because he cannot keep the centre of gravity between his feet?

Father. That is the precise reason why any person, whether old or young, falls. And hence you learn that a man stands much firmer with his feet a little apart than if they were quite close, for by separating them he increases the base. Hence also the difficulty of sustaining a tall body, as a walking cane, upon a narrow foundation.

Emma. How do rope and wire dancers, whom I have seen at the Circus, manage to balance themselves?

Father. They generally hold a long pole, with weights at each end, across the rope on which they dance, keeping their eyes fixed on some object, parallel to the rope, by which

means they know when their centre of gravity declines to one side of the rope or the other, and thus by the help of the pole, they are enabled to keep the centre of gravity over the base, narrow as it is. It is not however rope-dancers only that pay attention to this principle, but the most common actions of the people in general are regulated by it.

Charles. In what respects?

Father. We bend forward, when we go up stairs, or rise from our chair, for when we are sitting, our centre of gravity is on the seat, and the line of direction falls behind our base; we therefore lean forwards to bring the line of direction towards our feet. For the same reason a man carrying a burden on his back leans forward: and backward if he carries it on his breast. If the load be placed on one shoulder he leans to the other. If we slip or stumble with one foot, we naturally extend the opposite arm, making the same use of it as the rope-dancer does of his pole.

This property of the centre of gravity always endeavouring to descend, will account for appearances, which are sometimes exhibited to excite the surprise of spectators.

Emma. What are those, papa?

Father. One is, that of a double cone, appearing to roll up two inclined planes, forming an angle with each other, for as it rolls it sinks

between them, and by that means the centre of gravity is actually descending.

Let a body FE (Plate II. Fig. 13.) consisting of two equal cones uniting at their bases, be placed upon the edges of two straight smooth rulers, AB and CD, which at one end meet in an angle at A, and rest on a horizontal plane; and at the other are raised a little above the plane; the body will roll towards the elevated end of the rulers, and appear to ascend; the parts of the cone that rest on the rulers growing smaller as they go over a large opening, and thus letting it down, the centre of gravity descends. But you must remember that the height of the planes must be less than the radius of the base of the cone.

Charles. Is it upon this principle that a cylinder is made to roll up hill?

Father. Yes, it is; but this can be effected only to a small distance. If a cylinder of pasteboard, or very light wood AB, (Plate II. Fig. 11.) having its centre of gravity at *c*, be placed on the inclined plane CD, it will roll down the inclined plane, because a line of direction from that centre lies out of the base. If I now fill the little hole *e* above with a plug of lead, it will roll up the inclined plane, till the lead gets near the base, where it will lie still: because the centre of gravity, by means of the lead, is removed from *c* towards the plug, and therefore

is descending, though the cylinder is ascending.

Before I put an end to this subject, I will show you another experiment, which without understanding the principle of the centre of gravity cannot be explained. Upon this stick A, (Plate II. Fig. 12.) which, of itself, would fall, because its centre of gravity hangs over the table EF, I suspend a bucket B, fixing another stick *a*, one end in a notch between A and *k*, and the other against the inside of the pail at the bottom. Now you will see that the bucket will, in this position, be supported, though filled with water. For the bucket being pushed a little out of the perpendicular, by the stick *a*, the centre of gravity of the whole is brought under the table, and is consequently supported by it.

The knowledge of the principle of the centre of gravity in bodies, will enable you to explain the structure of a variety of toys which are put into the hands of children, such as the *little sawyer; rope-dancer; tumbler, &c.*

CONVERSATION XI.

On the Laws of Motion.

Charles. Are you now going, papa, to describe those machines, which you call *mechanical powers?*

Father. We must, I believe, defer that a day or two longer, as I have a few more general principles with which I wish you previously to be acquainted.

Emma. What are these, papa?

Father. In the first place, you must well understand what are denominated the three general laws of motion: the first of which is, "*that every body will continue in its state of rest, or of uniform motion, until it is compelled by some force to change its state.*"*

Charles. There is no difficulty of conceiving that a body, as this inkstand, in a state of rest,

* The author is aware that this Law of Motion is not admitted by some modern philosophers of high name; to him, however, their reasonings appear inconclusive. At any rate, in a work intended for very young minds, he thinks it a duty to avoid metaphysical distinctions: preferring, at all times, rather to guide them by matters of fact than to load their tender memories with curious and subtile theories.

must always remain so, if no external force be impressed upon it to give it motion. But I know of no example which will lead me to suppose, that a body once put into motion would of itself continue so.

Father. You will, I think, presently admit the latter part of the assertion, as well as the former, although it cannot be established by experiment.

Emma. I shall be glad to hear how this is.

Father. You will not deny that the ball which you strike from the trap, has no more power either to destroy its motion, or cause any change in its velocity, than it has to change its shape.

Charles. Certainly ; nevertheless, in a few seconds after I have struck the ball with all my force, it falls to the ground, and then stops.

Father. Do you find no difference in the time that is taken up before it comes to rest, even supposing your blow the same ?

Charles. Yes, if I am playing on the grass, it rolls to a less distance, than when I play on the smooth gravel.

Father. You find a like difference when you are playing at marbles, if you play in the gravel court, or on the even pavement in the arcade.

Charles. The marbles run so easily on the smooth stones in the arcade, that we can scarcely shoot with a force small enough.

Emma. And I remember Charles and my cousin were, last winter, trying how far they could shoot their marbles along the ice in the canal; and they went a prodigious distance, in comparison of that which they would have gone on the gravel, or even on the pavement in the arcade.

Father. Now these instances properly applied will convince you, that a body once put into motion, would go on for ever, if it were not compelled by some external force to change its state.

Charles. I perceive what you are going to say:—it is the rubbing or friction of the marbles against the ground which does the business. For on the pavement there are fewer obstacles than on the gravel, and fewer on the ice than on the pavement; and hence you would lead us to conclude, that if all obstacles were removed, they might proceed on for ever. But what are we to say of the ball, what stops that?

Father. Besides friction, there is another and still more important circumstance to be taken into consideration, which affects the ball, marbles, and every body in motion.

Charles. I understand you: that is the attraction of gravitation.

Father. It is: for from what we said when we conversed on that subject, it appeared that gravity has a tendency to bring every body in motion to the earth; consequently, in a few seconds,

your ball must come to the ground by that cause alone; but besides the attraction of gravitation, there is a resistance which the air, through which the ball moves, makes to its passage.

Emma. That cannot be much, I think.

Father. Perhaps, with regard to the ball struck from your brother's trap, it is of no great consideration, because the velocity is but small; but in all great velocities, as that of a ball from a musket or cannon, there will be a material difference between the theory and practice, if it be neglected in the calculation. Move your mamma's riding-whip through the air slowly, and you observe nothing to remind you that there is this resisting medium; but if you swing it with considerable swiftness, the noise which it occasions will inform you of the resistance it meets with from something, which is the atmosphere.

Charles. If I now understand you, the force which compels a body in motion to stop, is of three kinds; (1.) the attraction of gravitation; —(2.) the resistance of the air;—and (3.) the resistance it meets with from friction.

Father. You are quite right.

Charles. I have no difficulty of conceiving, that a body in motion, will not come to a state of rest, till it is brought to it by an external force, acting upon it in some way or other. I have seen a gentleman, when skating on very slippery ice, go a great way without any exertion to

himself, but where the ice was rough, he could not go half the distance without making fresh efforts.

Father. I will mention another instance or two on this law of motion. Put a basin of water into your little sister's wagon, and when the water is perfectly still, move the wagon, and the water, resisting the motion of the vessel, will at first rise up in the direction contrary to that in which the vessel moves. If, when the motion of the vessel is communicated to the water, you suddenly stop the wagon, the water, in endeavouring to continue the state of motion, rises up on the opposite side.

In like manner, if while you are sitting quietly on your horse, the animal starts forward, you will be in danger of falling off backward; but if while you are galloping along, the animal stops on a sudden, you will be liable to be thrown forward.

Charles. This I know by experience, but I was not aware of the reason of it till to-day.

Father. One of the first, and not least important uses of the principles of natural philosophy is, that they may be applied to, and will explain many of the common concerns of life.

We now come to the *second* law of motion, which is;—"*that the change of motion is proportional to the force impressed, and in the direction of that force.*"

Charles. There is no difficulty in this, for if

while my cricket-ball is rolling along after Henry has struck it, I strike it again, it goes on with increased velocity, and that in proportion to the strength which I exert on the occasion; whereas, if while it is rolling, I strike it back again, or give it a side blow, I change the direction of its course.

Father. In the same way, gravity, and the resistance of the atmosphere, change the direction of a cannon-ball from its course in a straight line, and bring it to the ground; and the ball goes to a further or less distance in proportion to the quantity of powder used.

The *third* law of motion is;—"*that to every action of one body upon another, there is an equal and contrary re-action.*" If I strike this table, I communicate to it (which you perceive by the shaking of the glasses) the motion of my hand; and the table re-acts against my hand just as much as my hand acts against the table.

If you press with your finger one scale of a balance to keep it in equilibrio with a pound weight in the other scale, you will perceive, that the scale pressed by the finger, acts against it with a force equal to a pound, with which the other scale endeavours to descend.

A horse drawing a heavy load, is as much drawn back by the load as he draws it forward.

Emma. I do not comprehend how the cart draws the horse.

Father. But the progress of the horse is im-

peded by the load, which is the same thing: for the force which the horse exerts would carry him to a greater distance in the same time, were he freed from the incumbrance of the load, and therefore, as much as his progress falls short of that distance, so much is he, in effect, drawn back by the re-action of the loaded cart.

Again, if you and your brother were in a boat, and if, by means of a rope, you were to attempt to draw another to you, the boat in which you were would be as much pulled towards the empty boat as that would be moved to you; and if the weight of the two boats were equal, they would meet in a point half way between the two.

If you strike a glass bottle with an iron hammer, the blow will be received by the hammer and the glass; and it is immaterial whether the hammer be moved against the bottle at rest, or the bottle be moved against the hammer at rest, yet the bottle will be broken, though the hammer be not injured, because the same blow, which is sufficient to break glass, is not sufficient to break or injure a mass of iron.

From this law of motion you may learn in what manner a bird, by the stroke of its wings, is able to support the weight of its body.

Charles. Pray explain this, papa.

Father. If the force with which it strikes the air below it, is *equal* to the weight of its body, then the re-action of the air upwards is likewise equal to it; and the bird being acted upon by

two *equal* forces in contrary directions, will rest between them. If the force of the stroke is *greater* than its weight, the bird will rise with the *difference* of these two forces; and if the stroke be *less* than its weight, then it will sink with the *difference*.

CONVERSATION XII.

On the Laws of Motion.

Charles. Are those laws of motion which you explained yesterday of great importance in natural philosophy?

Father. Yes, they are, and should be carefully committed to memory. They were assumed by Sir Isaac Newton, as the fundamental principles of mechanics, and you will find them at the head of all books written on these subjects. From these also, we are naturally led to some other branches of science, which, though we can but slightly mention, should not be wholly neglected. They are, in fact, but corollaries to the laws of motion.

Emma. What is a corollary, papa?

Father. It is nothing more than some truth clearly deducible from some other truth before demonstrated or admitted. Thus by the *first* law of motion, *every body must endeavour to continue in the state into which it is put, whether it be of rest, or uniform motion in a straight line:* from which it follows as a corollary, "that when we see a body move in a curve line, it must be acted upon by at least two forces."

Charles. When I whirl a stone round in a sling, what are the two forces which act upon the stone?

Father. There is the force, by which, if you let go the string, the stone will fly off in a right line; and there is the force of the hand, which keeps it in a circular motion.

Emma. Are there any of these circular motions in nature?

Father. The moon, and all the planets move by this law;—to take the moon as an instance. It has a constant tendency to the earth, by the attraction of gravitation, and it has also a tendency to proceed in a right line, by that projectile force impressed upon it by the Creator, in the same manner as the stone flies from your hand; now, by the joint action of these two forces it describes a circular motion.

Emma. And what would be the consequence, supposing the projectile force to cease?

Father. The moon must fall to the earth; and if the force of gravity were to cease acting upon

the moon, it would fly off into infinite space. Now the projectile force, when applied to the planets, is called the *centrifugal* force, as having a tendency to recede or fly from the centre; and the other force is termed the *centripetal* force, from its tendency to some point as a centre.

Charles. And all this is in consequence of the inactivity of matter, by which bodies have a tendency to continue in the same state they are in, whether of rest or motion?

Father. You are right; and this principle, which Sir Isaac Newton assumed to be in all bodies, he called their *vis inertiæ.*

Charles. A few mornings ago, you showed us that the attraction of the earth upon the moon* is 3600 times less than it is upon heavy bodies near the earth's surface. Now as this attraction is measured by the space fallen through in a given time, I have endeavoured to calculate the space which the moon would fall through in a minute, were the projectile force to cease.

Father. Well, and how have you brought it out?

Charles. A body falls 16 feet in the first second, consequently in a minute, or 60 seconds it would fall 60 times 60 feet, multiplied by 16, that is 3600 feet, which is to be multiplied by 16; and as the moon would fall through 3600 times less space in a given time than a body here, it would fall only 16 feet in the first *minute.*

* See Conversation IV.

Father. Your calculation is accurate. I will recall to your mind the *second* law, by which it appears, *that every motion or change of motion produced in a body, must be proportional to, and in the direction of, the force impressed*. Therefore, if a moving body receives an impulse in the direction of its motion, its velocity will be increased;—if in the contrary direction, its velocity will be diminished;—but if the force be impressed in a direction oblique to that in which it moves, then its direction will be between that of its former motion, and that of the new force impressed.

Charles. This I know from the observations I have made with my cricket-ball.

Father. By this second law of motion, you will easily understand; that if a body at rest receives two impulses, at the same time, from forces whose directions do not coincide, it will, by their joint action, be made to move in a line that lies between the direction of the forces impressed.

Emma. Have you any machine to prove this satisfactorily to the senses?

Father. There are many such invented by different persons, descriptions of which you will hereafter find in various books on these subjects. But it is easily understood by a figure. If on the ball A, (Plate II. Fig. 14.) a force be impressed, sufficient to make it move with a uniform velocity to the point B, in a second of

time; and if another force be also impressed on the ball, which alone would make it move to the point C, in the same time; the ball, by means of the two forces, will describe the line A D, which is a diagonal of the figure, whose sides are A C and A B.

Charles. How then is motion produced in the *direction of the force;* according to the second law, it ought to be in one case, in the direction A C, and in the other, in that of A B, whereas, it is in that of A D?

Father. Examine the figure a little attentively, carrying this in your mind, that for a body to move in the *same direction*, it is *not* necessary that it should move in the *same straight line;* but that it is sufficient to move *either* in that line, or in any one parallel to it.

Charles. I perceive then that the ball when arrived at D, has moved in the direction A C, because B D is parallel to A C; and also in the direction A B, because C D is parallel to it.

Father. And in no other possible situation but at the point D could this experiment be conformable to the second law of motion.

CONVERSATION XIII.

On the Laws of Motion.

Father. If you reflect a little upon what we said yesterday on the second law of motion, you will readily deduce the following corollaries: (Plate II. Fig 14.)

1. That if the forces be equal, and act at right angles to one another, the line described by the ball will be the diagonal of a *square*. But in all other cases, it will be the diagonal of a parallelogram of some kind.

2. By varying the angle, and the forces, you vary the form of your parallelogram.

Charles. Yes, papa; and I see another consequence, viz. that the motions of two forces acting conjointly in this way, are not so great as when they act separately.

Father. That is true, and you are led to the conclusion, I suppose, from the recollection, that in every triangle any two sides taken together are greater than the remaining side; and therefore you infer, and justly too, that the motions which the ball A must have received, had the forces been applied separately, would have been equal to A C and A B, or, which is the

same thing, to A C, and C D, the two sides of the triangle A D C, but by their joint action the motion is only equal to A D, the remaining side of the triangle.

Hence then you will remember, that in the *composition*, or adding together of forces, (as this is called,) motion is always lost; and in the *resolution* of any one force, as A D, into two others A C and A B, motion is gained.

Charles. Well, papa, but how is it that the heavenly bodies, the moon for instance, which is impelled by two forces, performs her motion in a circular curve round the earth, and not in a diagonal between the direction of the projectile force and that of the attraction of gravity to the earth.

Father. Because in the case just mentioned there was but the action of a single impulse in each direction, whereas the action of gravity on the moon is continual, and causes an accelerated motion, and hence the line is a curve.

Charles. Supposing, then, that A represent the moon, and A C the sixteen feet through which it would fall in a second by the attraction of gravity towards the earth, and A B represent the projectile force acting upon it for the same time. If A B and A C acted as single impulses, the moon would in that case describe the diagonal A D; but since these forces are constantly acting, and that of gravity is an accelerating force also, therefore, instead of the straight line A D,

the moon will be drawn into the curve line A *a* D. Do I understand the matter right?

Father. You do; and hence you easily comprehend how, by good instruments and calculation, the attraction of the earth upon the moon was discovered.

The *third* law of motion, viz. *that action and re-action are equal and in contrary directions*, may be illustrated by the motion communicated by the percussion of *elastic* and *non-elastic* bodies.

Emma. What are these, papa?

Father. *Elastic* bodies are those which have a certain spring, by which their parts, upon being pressed inwards, by percussion, return to their former state; this property is evident in a ball of wool or cotton, or in sponge compressed. *Non-elastic* bodies are those which, when one strikes another, do not rebound, but move together after the stroke.

Let two *equal* ivory balls *a* and *b* be suspended by threads; if *a* (PLATE II. Fig. 15.) be drawn a little out of the perpendicular, and let fall upon *b*, it will lose its motion by communicating it to *b*, which will be driven to a distance *c*, equal to that through which *a* fell; and hence it appears that the re-action of *b*, was equal to the action of *a* upon it.

Emma. But do the parts of the ivory balls yield by the stroke, or, as you call it, by the percussion?

Father. They do; for if I lay a little paint on *a*, and let it *touch* *b*, it will make but a very small speck upon it: but if it *fall* upon *b*, the speck will be much larger; which proves that the balls are elastic, and that a little hollow, or dent, was made in each by collision. If now two equal soft balls of clay, or glazier's putty, which are non-elastic, meet each other with equal velocities, they would stop and stick together at the place of their meeting, as their mutual actions destroy each other.

Charles. I have sometimes shot my white alley against another marble so plumply, that the marble has gone off as swiftly as the alley approached it, and that remained in the place of the marble. Are marbles, therefore, as well as ivory, elastic?

Father. They are.—If three elastic balls, *a*, *b*, *c*, (Plate III. Fig. 16.) be hung from adjoining centres, and c be drawn a little out of the perpendicular, and let fall upon *b*, then will *c* and *b* become stationary, and *a* will be driven to *o*, the distance through which *c* fell upon *b*.

If you hang any number of balls, as six, eight, &c. so as to touch each other, and if you draw the outside one away to a little distance and then let it fall upon the others, the ball on the opposite side will be driven off, while the rest remain stationary, so equally is the action and reaction of the stationary balls divided among them. In the same manner, if two are drawn

aside and suffered to fall on the rest, the opposite two will fly off, and the others remain stationary.

There is one other circumstance depending upon the action, and re-action of bodies, and also upon the *vis inertiæ* of matter, worth noticing: by some authors you will find it largely treated upon.

If I strike a blacksmith's anvil with a hammer, action and re-action being equal, the anvil strikes the hammer as forcibly as the hammer strikes the anvil.

If the anvil be large enough, I might lay it on my breast and suffer you to strike it with a sledge hammer with all your strength, without pain or risque, for the *vis inertiæ* of the anvil resists the force of the blow. But if the anvil were but a pound or two in weight, your blow would probably kill me.

CONVERSATION XIV.

On the Mechanical Powers.

Charles. Will you now, papa, explain the mechanical powers?

Father. I will, and I hope you have not forgotten what the *momentum* of a body is.

Charles. No; it is the force of a moving body, which force is to be estimated by the weight, multiplied into its velocity.

Father. Then a small body may have an equal momentum with one much larger?

Charles. Yes, provided the smaller body moves as much swifter than the larger one, as the weight of the latter is greater than that of the former.

Father. What do you mean when you say that one body moves swifter, or has a greater velocity than another?

Charles. That it passes over a greater space in the same time. Your watch will explain my meaning; the minute-hand travels round the dial plate in an hour, but the hour-hand takes twelve hours to perform its course in, consequently the velocity of the minute-hand is twelve times greater than that of the hour-hand; be-

cause, in the same time, viz, twelve hours, it travels twelve times the space that is gone through by the hour-hand.

Father. But this can be only true on the supposition, that the two circles are equal. In my watch, the minute-hand is longer than the other, and, consequently, the circle described by it is larger than that described by the hour-hand.

Charles. I see at once, that my reasoning holds good only in the case where the hands are equal.

Father. There is, however, a particular point of the longer hand, of which it may be said, with the strictest truth, that it has exactly twelve times the velocity of the extremity of the shorter.

Charles. That is the point, at which, if the remainder were cut off, the two hands would be equal. And, in fact, every different point of the hand describes different spaces in the same time.

Father. The little pivot on which the two hands seem to move (for they are really moved by different pivots, one within another) may be called the *centre of motion*, which is a fixed point; and the longer the hand is, the greater is the space described.

Charles. The extremities of the vanes of a wind-mill, when they are going very fast, are scarcely distinguishable, though the separate parts, nearer the mill, are easily discerned; this

is owing to the velocity of the extremities being so much greater than that of the other parts.

Emma. Did not the swiftness of the round-abouts, which we saw at the fair, depend on the same principle, viz. the length of the poles upon which the seats were fixed?

Father. Yes, the greater the distance at which these seats were placed from the centre of motion, the greater was the space which the little boys and girls travelled for their half-penny.

Emma. Then those in the second row had a shorter ride for their money, than those at the end of the poles.

Father. Yes, shorter as to space, but the same as to time. In the same way, when you and Charles go round the gravel-walk for half an hour's exercise, if he run, while you walk, he will, perhaps, have gone six or eight times round, in the same time that you have been but three or four times; now, as to time, your exercise has been equal, but he may have passed over double the space in the same time.

Charles. How does this apply to the explanation of the mechanical powers?

Father. You will find the application very easy:—without clear ideas of what is meant by *time* and *space*, it were in vain to expect you to comprehend the principles of mechanics.

There are six mechanical powers. The lever; the wheel and axle; the pulley; the inclined plane; the wedge; and the screw.

Emma. Why are they called mechanical powers?

Father. Because, by their means we are enabled *mechanically* to raise weights, move heavy bodies, and overcome resistances, which, without their assistance, could not be done.

Charles. But is there no limit to the assistance gained by these powers? for I remember reading of Archimedes, who said, that with a place for his fulcrum he would move the earth itself.

Father. Human power, with all the assistance which art can give, is very soon limited, and upon this principle, *that what we gain in power, we lose in time.* That is, if by your own unassisted strength, you are able to raise fifty pounds to a certain distance in one minute, and if by the help of machinery, you wish to raise 500 pounds to the same height, you will require ten minutes to perform it in; thus you increase your power ten-fold, but it is at the expense of time. Or, in other words, you are enabled to do that with one effort in ten minutes, which you could have done in ten separate efforts in the same time.

Emma. The importance of mechanics, then, is not so very considerable as one, at first sight, would imagine; since there is no real gain of force acquired by the mechanical powers.

Father. Though there be not any actual increase of force gained by these powers; yet, the

advantages which men derive from them are inestimable. If there are several small weights, manageable by human strength, to be raised to a certain height, it may be full as convenient to elevate them one by one, as to take the advantage of the mechanical powers in raising them all at once. Beeause, as we have shown, the same time will be necessary in both cases. But suppose you have a large block of stone of a ton weight to carry away, or a weight still greater, what is to be done?

Emma. I did not think of that.

Father. Bodies of this kind cannot be separated into parts proportionable to the human strength without immense labour, nor, perhaps, without rendering them unfit for those purposes to which they are to be applied. Hence then you perceive the great importance of the mechanical powers, by the use of which a man is able with ease to manage a weight many times greater than himself.

Charles. I have, indeed, seen a few men, by means of pulleys, and seemingly with no very great exertion, raise an enormous oak into a timber-carriage, in order to convey it to the dock-yard.

Father. A very excellent instance; for if the tree had been cut into such pieces as could have been managed by the natural strength of these men, it would not have been worth carrying to

Deptford or Chatham for the purpose of shipbuilding.

Emma. I acknowledge my error;—what is a fulcrum, papa?

Father. It is a *fixed point*, or prop, round which the other parts of a machine move.

Charles. The pivot, upon which the hands of your watch move, is a fulcrum then.

Father. It is, and you remember we called it also the centre of motion; the rivet of these scissors is also a fulcrum.

Emma. Is that a fixed point or prop?

Father. Certainly it is a fixed point, as it regards the two parts of the scissors; for that always remains in the same position, while the other parts move about it. Take the poker and stir the fire; now that part of the bar on which the poker rests is a fulcrum, for the poker moves upon it as a centre.

CONVERSATION XV.

Of the Lever.

Father. We will now consider the *Lever*, which is generally called the first mechanical power.

The *Lever* is any inflexible bar of wood, iron, &c. which serves to raise weights, while it is supported at a point by a prop or fulcrum, on which, as the centre of motion, all the other parts turn. A B (Plate III. Fig. 17.) will represent a lever, and the point C the fulcrum or centre of motion. Now, it is evident, if the lever turn on its centre of motion C, so that A comes into the position *a*; B at the same time must come into the position *b*. If both the arms of the lever be equal, that is, if A C is equal to B C, there is no advantage gained by it, for they pass over equal spaces in the same time; and according to the fundamental principle already laid down (p. 76) "as advantage or power is gained, time must be lost:" therefore, no time being lost by a lever of this kind, there can be no power gained.

Charles. Why then is it called a mechanical power?

Father. Strictly speaking perhaps it ought not to be numbered as one. But it is usually reckoned

among them, having the fulcrum between the weight and the power, which is the distinguishing property of levers of the first kind. And when the fulcrum is exactly the middle point between the weight and power, it is the common balance: to which, if scales be suspended at A B, it is fitted for weighing all sorts of commodities.

Emma. You say it is a lever of the *first* kind; are there several sorts of levers?

Father. There are three sorts; some persons reckon four, the fourth however, is but a bended one of the first kind. A lever of the *first* kind (Plate III. Fig. 18, 19.) has the fulcrum between the weight and power.

The *second* kind of lever (Plate III. Fig. 20.) has the fulcrum at one end, the power at the other, and the weight between them.

In the *third* kind (Plate III. Fig. 21.) the power is between the fulcrum and the weight.

Of Lever's powers the different sorts are three,
The *first* in steel-yards and in scales you see;
The best and *second* is the miller's lift,
Where *power* and *fulcrum* to each end you shift;
And in the *third*, the worst of all, my friend,
You find the *weight* and *fulcrum* at each end.

Let us take the lever of the first kind, (Fig. 18.) which if it be moved into the position *a b*, by turning on its fulcrum C, it is evident that while A has travelled over the short space A *a*, B has travelled over the greater space B *b*, which

spaces are to one another, exactly in proportion to the length of the arms A C and B C. If now you apply your hand first to the point A, and afterwards to B, in order to move the lever into the position *a b*, using the same velocity in both cases, you will find that the time spent in moving the lever when the hand is at B, will be as much greater, as that spent when the hand is at A, as the arm B C is longer than the arm A C, but then the exertion required will, in the same proportion, be less at B than at A.

Charles. The arm B C appears to be four times the length of A C.

Father. Then it is a lever which gains power in the proportion of four to one. That is, a single pound weight applied to the end of the arm B C, as at P, will balance four pounds suspended at A, as W.

Charles. I have seen workmen move large pieces of timber to very small distances, by means of a long bar of wood or iron; is that a lever?

Father. It is; they force one end of the bar under the timber, and then place a block of wood, stone, &c. beneath, and as near the same end of the lever as possible, for a fulcrum, applying their own strength to the other: and power is gained in proportion as the distance from the fulcrum to the part where the men apply their strength, is greater than the distance from the fulcrum to that end under the timber.

Charles. It must be very considerable, for I have seen two or three men move a tree, in this way, of several tons weight I should think.

Father. That is not difficult; for supposing a lever to gain the advantage of twenty to one, and a man by his natural strength is able to move but a hundred weight, he will find that by a lever of this sort, he can move twenty hundred weight or a ton; but for single exertions, a strong man can put forth a much greater power, than that which is sufficient to remove a hundred weight; and levers are also frequently used, the advantage gained by which is still more considerable than twenty to one.

Charles. I think you said, the other day, that the common steel-yard made use of by the butcher, is a lever.

Father. I did; the short arm A C (Plate III. Fig. 19.) is, by an increase in size, made to balance the longer one B C, and from C, the centre of motion, the divisions must commence. Now if B C be divided into as many parts as it will contain, each equal to A C; a single weight, as a pound P, will serve for weighing any thing as heavy as itself, or as many times heavier as there are divisions in the arm C. If the weight P be placed at the division 1, in the arm B C, it will balance one pound in the scale at A: if it be removed to 3, 5, or 7, it will balance 3, 5, or 7 pounds in the scale; for these divisions being respectively 3, 5, or 7 times the distance from the

centre of motion C, that A is, it becomes a lever, which gains advantage at those points, in the proportion of 3, 5, and 7. If now the intervals between the divisions on the longer arm be subdivided into halves, quarters, &c. any weight may be accurately ascertained to halves, quarters of pounds, &c.

CONVERSATION XVI.

Of the Lever.

Emma. What advantage has the steel-yard, which you described in our last conversation, over a pair of scales?

Father. It may be much more readily removed from place to place; it requires no apparatus, and only a single weight for all the purposes to which it can be applied. Sometimes the arms are not of equal weight. In that case the weight P must be moved along the arm B C, till it exactly balance the other arm without a weight, and in that point a notch must be made, marking over it a cipher O, from whence the divisions must commence.

Charles. Does there require great accuracy in the manufacture of instruments of this kind?

Father. Yes, of such importance is it to the public, that there should be no error or fraud by means of false weights or false balances, that it is the business of certain public officers to examine at stated seasons the weights, measures, &c. of every shopkeeper in the land. Yet it is to be feared that after all precautions, much fraud is practised on the unsuspecting.

Emma. I one day last summer bought, as I supposed, a pound of cherries at the door, but Charles thinking they were not a pound, we tried them in your scales and found but twelve ounces, or three quarters, instead of a pound, and yet the scale went down as if the man had given me full weight. How was that managed?

Father. It might be done many ways: by short weights;—or by the scale in which the fruit was put, being heavier than the other;—but fraud may be practised with honest weights and scales, by making the arm of balance on which the weights hang, shorter than the other, for then a pound weight will be balanced by as much less fruit than a pound, as that arm is shorter than the other; this was probably the method by which you were cheated.

Emma. By what method could I have discovered this cheat?

Father. The scales when empty are exactly balanced, but when loaded, though still in equi-

librio, the weights are unequal, and the deceit is instantly discovered by changing the weights to the contrary scales. I will give you a rule to find the true weight of any body by such a false balance, the reason of the rule you will understand hereafter: "*Find the weights of the body by both scales, multiply them together, and then find the square root of the product, which is the true weight.*"

Charles. Let me see if I understand the rule: suppose a body weigh 16 ounces in one scale, and in the other 12 ounces and a quarter, I multiply 16 by 12 and a quarter, and I get the product 196, the square root of which is 14: for 14 multiplied into itself gives 196; therefore the true weight of the body is 14 ounces.

Father. That is just what I meant.—To the lever of the first kind may be referred many common instruments, such as scissors, pincers, snuffers, &c. which are made by two levers acting contrary to one another.

Emma. The rivet is the fulcrum, or centre of motion, the hand the power used, and whatever is to be cut, is the resistance to be overcome.

Charles. A poker stirring the fire is also a lever, for the bar is the fulcrum, the hand the power, and the coals the resistance to be overcome.

Father. We now proceed to levers of the second kind, in which the fulcrum c (Fig. 20.) is

at one end, the power P applied at the other B, and the weight to be raised W, somewhere between the fulcrum and the power.

Charles. And how is the advantage gained to be estimated in this lever?

Father. By looking at the figure you will find that power or advantage is gained in proportion as the distance B, the point at which the power P acts, is greater than the distance of the weight W from the fulcrum.

Charles. Then if the weight hang at one inch from the fulcrum, and the power acts at five inches from it, the power gained is five to one, or one pound at P will balance five at W.

Father. It will; for you perceive that the power passes over five times as great a space as the weight, or while the point A in the lever moves over one inch, the point B will move over five inches.

Emma. What things in common use are to be referred to the lever of the second kind?

Father. The most common and useful of all things; every door, for instance, which turns on hinges is a lever of this sort. The hinges may be considered as the fulcrum or centre of motion, the whole door is the weight to be moved, and the power is applied to that side on which the lock is usually fixed.

Emma. Now I see the reason why there is considerable difficulty in pushing open a heavy

door, if the hand is applied to the part next the hinges, although it may be opened with the greatest ease in the usual method.

Charles. This sofa, with sister upon it, represents a lever of the second kind.

Father. Certainly, if while she is sitting upon it, in the middle, you raise one end, while the other remains fixed as a prop or fulcrum. To this kind of lever may be also reduced nut-crackers; oars; rudders of ships; those cutting knives which have one end fixed in a block, such as are used for cutting chaff, drugs, wood for pattens, &c.

Emma. I do not see how oars and rudders are levers of this sort.

Father. The boat is the weight to be moved, the water is the fulcrum, and the waterman at the handle the power. The masts of ships are also levers of the second kind, for the bottom of the vessel is the fulcrum, the ship the weight, and the wind acting against the sail is the moving power.

The knowledge of this principle may be useful in many situations and circumstances in life:—if two men unequal in strength have a heavy burden to carry on a pole between them, the ability of each may be consulted by placing the burden as much nearer to the stronger man, as his strength is greater than that of his partner.

Emma. Which would you call the prop in this case?

Father. The stronger man, for the weight is

nearest to him, and then the weaker must be considered as the power. Again, two horses may be so yoked to a carriage that each shall draw a part proportional to his strength, by dividing the beam in such a manner, that the point of *traction*, or drawing, may be as much nearer to the stronger horse than to the weaker, as the strength of the former exceeds that of the latter.

We will now describe the third kind of lever. In this the prop or fulcrum C (Fig. 21.) is at one end, the weight W at the other, and the power P is applied at B somewhere between the prop and weight.

Charles. In this case, the weight being further from the centre of motion than the power, must pass through more space than it.

Father. And what is the consequence of that?

Charles. That the power must be greater than the weight and as much greater as the distance of the weight from the prop exceeds the distance of the power from it, that is, to balance a weight of three pounds at A, there will require the exertion of a power P, acting at B, equal to five pounds.

Father. Since then a lever of this kind is a disadvantage to the moving power, it is but seldom used, and only in cases of necessity; such as in that of a ladder, which being fixed at one end against a wall or other obstacle, is by the

strength of a man's arm raised into a perpendicular situation. But the most important application of this third kind of lever, is manifest in the structure of the limbs of animals, particularly in those of man; to take the arm as an instance; when we lift a weight by the hand, it is effected by means of muscles coming from the shoulder blade, and terminating about one-tenth as far below the elbow as the hand is: now the elbow being the centre of motion round which the lower part of the arm turns,' according to the principle just laid down, the muscles must exert a force ten times as great as the weight that is raised. At first view this may appear a disadvantage, but what is lost in power is gained in velocity, and thus the human figure is better adapted to the various functions it has to perform.

CONVERSATION XVII.

Of the Wheel and Axis.

Father. Well, Emma, do you understand the principle of the lever, which we discussed so mueh at large yesterday?

Emma. The lever gains advantage, in proportion to space passed through by the acting power; that is, if the weight to be raised, be at the distance of one inch from the fulcrum, and the power is applied nine inches distant from it, then it is a lever, which gains advantage as 9 to 1, because the space passed through by the *power* is nine times greater than that passed through by the weight; and, therefore, what is lost in time by passing through a greater space, is gained in power.

Father. You recollect also, what the different kinds of levers are, I hope.

Emma. I shall never see the fire stirred without thinking of a simple lever of the first kind; my scissors will frequently remind me of a combination of two levers of the same sort. The opening and shutting of the door, will prevent me from forgetting the nature of the lever of the second kind, and, I am sure that I shall never see a workman raise a ladder against a house, without recollecting the third sort of lever. Besides, I believe a pair of tongs is a lever of this kind.

Father. You are right; for the fulcrum is at the joint, and the power is applied between that, and parts used in taking up coals, &c.—Can you Charles, tell us how the principle of *momentum* applies to the lever?

Charles. The *momentum* of a body is estimated by its weight, multiplied into its velocity;

and the velocity must be calculated by the space passed through in a given time. Now, if I examine the lever, (Fig. 18. 20.) and consider it as an inflexible bar turning on a centre of motion, it is evident, that the same time is used for the motion both of the weight and the power, but the spaces passed over are very different; that which the power passes through, being as much greater as that passed by the weight, as the length of the distance of the power from the prop, is greater than the distance of the weight from the prop; and the velocities being as the spaces passed in the same time, must be greater in the same proportion. Consequently, the velocity of P, the power, multiplied into its weight, will be equal to the smaller velocity of W, multiplied into its weight, and thus their momenta being equal, they will balance one another.

Father. This applies to the first and second kind of lever; what do you say to the third?

Charles. In the third, the velocity of the power P, (Fig. 21.) being less than that of the weight W, it is evident, in order that their momenta may be equal, that the weight acting at P, must be as much greater than that of W, as A C is less than B C, and then they will be in equilibrio.

Father. The second mechanical power is the *Wheel and Axis*, which gains power in proportion as the circumference of the wheel is greater

than that of the axis; this machine may be referred to the principle of the lever; A B (Plate III. Fig. 23.) is the wheel, Q D its axis, and if the circumference of the wheel be eight times as great as that of the axis, then a single pound P, will balance a weight W, of eight pounds.

Charles. Is it by an instrument of this kind that water is drawn from those deep wells so common in many parts of the country?

Father. It is; but as in most cases of this kind only a single bucket is raised at once, there requires but little power in the operation, and therefore, instead of a large wheel as A B, an iron handle fixed at B is made use of, which, you know, by its circular motion, answers the purpose of a wheel.

Charles. I once raised some water by a machine of this kind, and I found, that as the bucket ascended nearer the top the difficulty increased.

Father. That must always be the case, where the wells are so deep as to cause, in the ascent, the rope to coil more than once the length of the axis, because the advantage gained is in proportion as the circumference of the wheel is greater than that of the axis; so that if the circumference of the wheel be 12 times greater than that of the axis, 1 pound applied at the former will balance 12 hanging at the latter; but by the coiling of the rope round the axis, the *difference* between the circumference of the wheel, and

that of the axis, continually diminishes, consequently the advantage gained is less every time a new coil of rope is wound on the whole length of the axis; this explains why the difficulty of drawing the water, or any other weight, increases as it ascends nearer the top.

Charles. Then by diminishing the axis, or by increasing the length of the handle, advantage is gained?

Father. Yes, by either of those methods you may gain power, but it is very evident, that the axis cannot be diminished beyond a certain limit, without rendering it too weak to sustain the weight; nor can the handle be managed, if it be constructed on a scale much larger than what is commonly used.

Charles. We must, then, have recourse to the wheel with spikes standing out of it at certain distances from each other to serve as levers.

Father. You may by this means increase your power according to your wish, but it must be at the expense of time, for you know that a simple handle may be turned several times, while you are pulling the wheel round once. To the principle of the *wheel and axis,* may be referred the capstan windlass, and all those numerous kinds of cranes, which are to be seen at the different wharves on the banks of the Thames.

Rous'd from repose, aloft the sailors swarm,
And with their *levers* soon the *windlass* arm.

The order given, up-springing with a bound
They lodge the bars, and wheel their engines round:
At every turn the clanging pauls resound,
Uptorn reluctant from its oozy cave
The pond'rous anchor rises o'er the wave.

FALCONER'S SHIPWRECK.

Charles. I have seen a crane, which consists of a wheel large enough for a man to walk in.

Father. In this the weight of the man, or men (for there are sometimes two or three,) is the moving power; for, as the man steps forwards, the part upon which he treads becomes the heaviest, and consequently descends till it be the lowest. On the same principle, you may see at the door of many bird-cage makers, a bird, by its weight, give a wicker cage a circular motion; now, if there were a small weight suspended to the axis of the cage, the bird by its motion would draw it up, for as it hops from the bottom bar to the next, its *momentum* causes that to descend, and thus the operation is performed, both with regard to the cage, and to those large cranes which you have seen.

Emma. Is there no danger if the man happen to slip?

Father. If the weight be very great, a slip with the foot may be attended with very dangerous consequences. To prevent which, there is generally fixed at one end of the axis a little wheel G, (Fig. 22.) called a ratchet-wheel; with a catch H, to fall into its teeth; this will at any

time support the weight in case of an accident. Sometimes, instead of men walking within the great wheel, cogs are set round it on the outside, and a small trundle wheel made to work in the cogs, and to be turned by a winch.

Charles. Are there not other sorts of cranes in which all danger is avoided?

Father. The crane is a machine of such importance to the commercial concerns of this country, that new inventions of it are continually offered to the public: I will, when we go to the library, show you in the 10th vol. of the Transactions of the Society for the Encouragement of Arts and Sciences, an engraving of a safe, and, I believe, truly excellent crane; it was invented by a friend of mine, Mr. James White, who possessed a most extraordinary genius for mechanics, and who formerly offered his services to a noble Duke, then at the head of the Board of Ordnance, but they being rejected, he went to the Continent, where he is very profitably exercising his talents.

Charles. But you said that this mechanical power might be considered as a lever of the first kind.

Father. I did; and if you conceive the wheel and axis (Fig. 22.) to be cut through the middle in the direction A B; F G B (Plate III. Fig. 23.) will represent a section of it. A B is a lever, whose centre of motion is C; the weight W, sustained by the rope A W, is applied at the distance

C A, the radius of the axis; and the power P, acting in the direction B P, is applied at the distance C B, the radius of the wheel: therefore, according to the principle of the lever, the power will balance the weight, when it is as much less than the weight, as the distance C B is greater than the distance of the weight A C.

CONVERSATION XVIII.

Of the Pulley.

Father. The third mechanical power, the *pulley*, may be likewise explained on the principle of the lever. The line A B (Plate IV. Fig 24.) may be conceived to be a lever, whose arms A C and B C are equal, and C the fulcrum, or centre of motion. If now two equal weights W and P, be hung on the cord passing over the pulley, they will balance one another, and the fulcrum will sustain both.

Charles. This pulley then, like the common balance, gives no advantage.

Father. From the single *fixed* pulley no mechanical advantage is derived; it is nevertheless

of great importance in changing the direction of a power, and is very much used in buildings for drawing up small weights, it being much easier for a man to raise such burdens by means of a single pulley, than to carry them up a long ladder.

Emma. Why is it called a mechanical power?

Father. Though a single fixed pulley gives no advantage, yet when it is not fixed, or when two more are combined into what is called a system of pulleys, they then possess all the properties of the other mechanical powers. Thus in C D B (Plate IV. Fig. 25.) C is the fulcrum, therefore a power P, acting at B, will sustain a double weight W, acting at A, for B C is double the distance of A C from the fulcrum.

Again it is evident, in the present case, that the whole weight is sustained by the cord E D F, and whatever sustains half the cord, sustains also half the weight; but one half is sustained by the fixed hook E, consequently the power at P has only the other half to sustain, or in other words, any given power at P will keep in equilibrio a double weight at W.

Charles. Is the velocity of P double that of W?

Father. Undoubtedly; if you compare the space passed through by the hand at P with that passed by W, you will find that the former is just double the latter, and therefore the *momenta* of the power and weight, as in the lever, are equal.

Charles. I think I see the reason of this, for if the weight be raised an inch, or a foot, both sides of the cord must also be raised an inch, or foot, but this cannot happen without that part of the cord at P passing through two inches, or two feet of space.

Father. You will now easily infer from what has been already shown of the single *moveable* pulley, that in a system of pulleys, the power gained must be estimated, by doubling the number of pulleys in the lower or moveable block. So that when the fixed block x (Plate IV. Fig. 26.) contains two pulleys which only turn on their axes, and the lower block *y* contains also two pulleys, which not only turn on their axes, but also *rise* with the weight, the advantage is as four: that is, a single pound at P will sustain four at W.

Charles. In the present instance also I perceive, that by raising W an inch, there are four ropes shortened each an inch, and therefore the hand must have passed through four inches of space in raising the weight a single inch; which establishes the maxim, that what is gained in power is lost in space. But, papa, you have only talked of the power of balancing or sustaining the weight, something more must, I suppose, be added to raise it.

Father. There must: considerable allowance must also be made for the friction of the cords, and of the pivots, or axes, on which the pulleys

turn. In the mechanical powers, in general, one-third of power must be added for the loss sustained by friction, and for the imperfect manner in which machines are generally constructed. Thus, if by *theory* you gain a power of 600: in *practice*, you must reckon only upon 400. In those pulleys which we have been describing, writers have taken notice of three things, which take much from the general advantage and convenience of pulleys as a mechanical power. The *first* is, that the diameters of the axes, bear a great proportion to their own diameters. The *second* is, that in working they are apt to rub against one another, or against the side of the block. And the *third* disadvantage is the stiffness of the rope that goes over and under them.

The first two objections have been, in a great degree, removed by the concentric pulley, invented by Mr. James White: B (Plate IV. Fig. 27.) is a solid block of brass, in which grooves are cut, in the proportion of 1, 3, 5, 7, 9, &c. and A is another block of the same kind, whose grooves are in the proportion of 2, 4, 6, 8, 10, &c. and round these grooves a cord is passed, by which means they answer the purpose of so many distinct pulleys, every point of which moving with the velocity of the string in contact with it, the whole friction is removed to the two centres of motion of the blocks A and B; besides it is of no small advantage, that the pulleys being all of

one piece, there is no rubbing one against the other.

Emma. Do you calculate the power gained by this pulley, in the same method as with the common pulleys?

Father. Yes, for pulleys of every kind, the rule is general, the advantage gained is found by doubling the number of the pulleys in the lower block: in that before you there are six grooves, which answer to as many distinct pulleys, and consequently the power gained is twelve, or one pound at P will balance twelve pounds at W.

CONVERSATION XIX.

Of the Inclined Plane.

Father. We may now describe the inclined plane, which is the fourth mechanical power.

Charles. You will not be able, I think, to reduce this also to the principle of the lever.

Father. No, it is a distinct principle, and some writers on these subjects reduce at once the six mechanical powers to two, viz. the lever and inclined plane.

Emma. How do you estimate the advantages gained by this mechanical power?

Father. The method is very easy, for just as much as the length of the plane exeeds its perpendicular height, so much is the advantage gained. Suppose A B (Plate IV. Fig. 28.) is a plane standing on the table, and C D another plane inclined to it; if the length C D be three times greater than the perpendicular height; then the cylinder E will be supported upon the plane C D, by a weight equal to the third part of its own weight.

Emma. Could I then draw up a weight on such a plane with the third part of the strength that I must exert in lifting it up at the end?

Father. Certainly, you might; allowance, however, must be made for overcoming the friction; but then you perceive, as in other mechanical powers, that you will have three times the space to pass over, or that as you gain power you will lose time.

Charles. Now I understand the reason why sometimes there are two or three strong planks laid from the street to the ground-floor of warehouses, making therewith an inclined plane, on which heavy packages are raised or lowered.

Father. The inclined plane is chiefly used for raising heavy weights to small heights, for in warehouses situated in the upper part of build-

ings, cranes and pulleys are better adapted for the purpose.

Charles. I have sometimes, papa, amused myself by observing the difference of time which one marble has taken to roll down a smooth board, and another which has fallen by its own gravity without any support.

Father. And if it were a long plank, and you took care to let both marbles drop from the hand at the same instant, I dare say you found the difference very evident.

Charles. I did, and now you have enabled me to account for it very satisfactorily, by showing me that as much more time is spent in raising a body along an inclined plane, than in lifting it up at the end, as that plane is longer than its perpendicular height. For I take it for granted that the rule holds in the ascent as well as in the descent.

Father. If you have any doubt remaining, a few words will make every thing clear. Suppose your marbles placed on a plane, perfectly horizontal, as on this table, they will remain at rest wherever they are placed: now if you elevated the plane in such a manner that its height should be equal to half the length of the plane, it is evident from what has been shown before, that the marbles would require a force equal to half their weight to sustain them in any particular position: suppose then the plane perpendicular to the table, the marbles will descend

with their whole weight, for now the plane contributes in no respect to support them, consequently they would require a power equal to their whole weight to keep them from descending.

Charles. And the swiftness with which a body falls is to be estimated by the force with which it is acted upon?

Father. Certainly, for you are now sufficiently acquainted with philosophy to know that the effect must be estimated from the cause. Suppose an inclined plane is thirty-two feet long, and its perpendicular height is sixteen feet, what time will a marble take in falling down the plane, and also in descending from the top to the earth by the force of gravity?

Charles. By the attraction of gravitation, a body falls sixteen feet in a second (see p. 41.) therefore the marble will be one second in falling perpendicularly to the ground; and as the length of the plane is double its height, the marble must take two seconds to roll down it.

Father. I will try you with another example. If there be a plane 64 feet perpendicular height, and 3 times 64, or 192 feet long, tell me what time a marble will take in falling to the earth by the attraction of gravity, and how long it will be in descending down the plane?

Charles. By the attraction of gravity it will fall in two seconds; because, by multiplying the sixteen feet which it falls in the first second, by

the square of two seconds, (the time) or four, I get sixty-four, the height of the plane. But the plane being three times as long as it is perpendicularly high, it must be three times as many seconds in rolling down the plane, as it was in descending freely by the force of gravity, that is, six seconds.

Emma. Pray, papa, what common instruments are to be referred to this mechanical power, in the same way, as scissors, pincers, &c. are referred to the lever?

Father. Chisels, hatchets, and whatever other sharp instruments which are chamfered, or sloped down to an edge on one side only, may be referred to the principle of the inclined plane.

CONVERSATION XX.

Of the Wedge.

Father. The next mechanical power is the *wedge*, which is made up of the two inclined planes, D E F G and C E F G (Plate IV. Fig. 29.) joined together at their bases *e* E F G : D C is the whole thickness of the wedge at its back A B C D, where the power is applied, and D F and C F

are the length of its sides; now there will be an equilibrium between the power impelling the wedge downward, and the resistance of the wood, or other substance acting against its sides, when the thickness D C of the wedge is to the length of the two sides, or, which is the same thing, when half the thickness D E of the wedge at its back is to the length of D F one of its sides, as the power is to its resistance.

Charles. This is the principle of the inclined plane.

Father. It is, and notwithstanding all the disputes which the methods of calculating the advantage gained by the wedge have occasioned, I see no reason to depart from the opinion of those who consider the wedge as a double inclined plane.

Emma. I have seen people cleaving wood with wedges, but they seem to have no effect, unless great force and great velocity are also used.

Father. No, the power of the attraction of cohesion, by which the parts of wood stick together, is so great, as to require a considerable *momentum* to separate them. Did you observe nothing else in the operation worthy of your attention?

Charles. Yes, I also took notice that the wood generally split a little below the place to which the wedge reached.

Father. This happens in cleaving most kinds

of wood, and then the advantage gained by this mechanical power, must be in proportion as the length of the sides of the cleft in the wood is greater than the length of the whole back of the wedge. There are other varieties in the action of the wedge; but, at present, it is not necessary to refer to them.

Emma. Since you said that all instruments which sloped off to an edge on one side only, were to be explained by the principle of the inclined plane; so, I suppose, that those which decline to an edge on both sides, must be referred to the principle of the wedge.

Father. They must, which is the case with many chisels, and almost all sorts of axes, &c.

Charles. Is the wedge much used as a mechanical power?

Father. It is of great importance in a vast variety of cases, in which the other mechanical powers are of no avail; and this arises from the momentum of the blow, which is greater, beyond comparison, than the application of any dead weight or pressure, such as is employed in the other mechanical powers. Hence it is used in splitting wood, rocks, &c. and even the largest ship may be raised to a small height by driving a wedge below it. It is also used for raising up the beam of a house, when the floor gives way, by reason of too great a burden being laid upon it. It is usual also in separating large mill stones from the siliceous sand-rocks

in some parts of Derbyshire, to bore horizontal holes under them in a circle, and fill these with pegs or wedges made of dry wood, which gradually swell by the moisture of the earth, and in a day or two lift up the mill-stone without breaking it; to this practice Dr. Darwin alludes:

> Climb the rude steeps, the granite-cliffs surround,
> Pierce with steel points, with wooden *wedges* wound.
>
> BOTANIC GARDEN.

CONVERSATION XXI.

Of the Screw.

Father. Let us now examine the properties of the sixth and last mechanical power, the *screw;* which, however, cannot be called a simple mechanical power, since it is never used without the assistance of a lever or winch; by which it becomes a compound engine, of great power in pressing bodies together, or in raising great weights. A B (Plate IV. Fig. 30.) is the

representation of one, together with the lever D F.

Emma. You said just now, papa, that all the mechanical powers were reducible either to the lever or inclined plane, how can the screw be referred to either?

Father. The screw is composed of two parts, one of which, A B, is called the screw, and consists of a spiral protuberance, called the *thread*, which may be supposed to be wrapt round a cylinder; the other part C D, called the *nut*, is perforated to the dimensions of the cylinder; and in the internal cavity is also a spiral groove adapted to receive the thread. Now if you cut a slip of writing-paper in the form of an inclined plane *a b c* (Fig. 30.) and then wrap it round a cylinder of wood, you will find that it makes a spiral answering to the spiral part of the screw; moreover, if you consider the ascent of the screw, it will be evident, that it is precisely the ascent of an inclined plane.

Charles. By what means do you calculate the advantage gained by the screw?

Father. There are, at first sight, evidently two things to be taken into consideration; the first is the distance between the threads of the screw;—and the second is the length of the lever.

Charles. Now I comprehend pretty clearly how it is an inclined plane, and that its ascent

is more or less easy as the threads of the spiral are nearer or farther distant from each other.

Father. Well then, let me examine by a question, whether your conceptions be accurate; suppose two screws, the circumference of whose cylinders are equal to one another; but in one, the distance of the threads to be an inch apart; and that of the threads of the other only one-third of an inch; what will be the difference of the advantage gained by one of the screws over the other?

Charles. The one whose threads are three times nearer than those of the other, must, I should think, give three times the most advantage.

Father. Give me the reason for what you assert.

Charles. Because, from the principle of the inclined plane, I learnt that if the *height* of two planes were the same, but the length of one, twice, thrice, or four times greater than that of the other, the mechanical advantage gained by the longer plane would be two, three, or four times more than that gained by the shorter. Now, in the present case, the height gained in both *screws* is the same, one inch, but the space passed in that, three of whose threads go to an inch, must be three times as great as the space passed in the other; therefore, as space is passed, or time lost, just in proportion to the advantage gained, I infer that three

times more advantage is gained by the screw the threads of which are one-third of an inch apart, than by that whose threads are an inch apart.

Father. Your inference is just, and naturally follows from an accurate knowledge of the principle of the inclined plane. But we have said nothing about the lever.

Charles. This seemed hardly necessary, it being so obvious to any one who will think a moment, that power is gained by that, as in levers of the first kind, according to the length F D from the nut.

Father. Let us now calculate the advantage gained by a screw, the threads of which are half an inch distance from one another, and the lever 7 feet long.

Charles. I think you once told me, that if the radius of a circle was given, in order to find the circumference, I must multiply that radius by 6.

Father. I did; for though that is not quite enough, yet it will answer all common purposes, till you are a little more expert in the use of decimals.

Charles. Well, then, the circumference of the circle made by the revolution of the lever will be 7 feet, multiplied by 6, which is 42 feet, or 504 inches; but, during this revolution, the screw is raised only half an inch, therefore the space passed by the moving power, will be 1008 times

greater than that gone through by the weight, consequently the advantage gained is 1008, or one pound applied to the lever will balance 1008 pounds acting against the screw.

Father. You perceive that it follows as a corollary from what you have been saying, that there are two methods by which you may increase the mechanical advantage of the screw.

Charles. I do;—it may be done either by taking a longer lever, or by diminishing the distance of the threads of the screw.

Father. Tell me the result then, supposing the threads of the screw so fine as to stand at the distance of but one quarter of an inch asunder; and that the length of the lever were 8 feet instead of 7.

Charles. The circumference of the circle made by the lever will be 8 multiplied by 6, equal to 48 feet or 576 inches, or 2304 quarter inches, and as the elevation of the screw is but one quarter of an inch, the space passed by the power, will, therefore, be 2304 times greater than that passed by the weight, which is the advantage gained in this instance.

Father. A child, then, capable of moving the lever sufficiently to overcome the friction, with the addition of a power equal to one pound, will be able to raise 2304 pounds, or something more than 20 hundred weight and a half. The strength of a powerful man would be able to do 20 or 30 times as much more.

Charles. But I have seen at Mr. W——'s paper-mills, to which I once went, six or eight men use all their strength in turning a screw, in order to press the water out of the newly made paper. The power applied in that case must have been very great indeed.

Father. It was; but I dare say that you are aware that it cannot be estimated, by multiplying the power of one man by the number of men employed.

Charles. That is, because the men standing by the side of one another, the lever is shorter to every man the nearer he stands to the screw, consequently, though he may exert the same strength, yet it is not so effectual in moving the machine, as the exertion of him who stands nearer to the extremity of the lever.

Father. The true method, therefore, of calculating the power of this machine, aided by the strength of these men, would be to estimate accurately the power of each man according to his position, and then adding all these separate advantages together for the total power gained.

Emma. A machine of this kind, is, I believe, used by book-binders, to press the leaves of the books together before they are stitched?

Father. Yes, it is found in every book-binder's work-shop, and is particularly useful where persons are desirous of having small books reduced to a still smaller size for the pocket. It is also the principal machine used for coining money;—

for taking off copper-plate prints; and for printing in general.

Charles. I remember Dr. Darwin's description of coining:

> With iron lips his rapid rollers seize
> The lengthening bars, in thin expansion squeeze;
> Descending *screws* with pond'rous fly-wheels wound
> The tawny plates, the new medallions round;
> Hard dies of steel the cupreous circles cramp,
> And with quick fall his massy hammers stamp.
> The Harp, the Lily, and the Lion join,
> And George, and Britain guard the sterling coin.
>
> Botanic Garden.

Father. These lines are descriptive of Mr. Boulton's magnificent apparatus for coining; the whole machinery is worked by an improved steam-engine, which rolls the copper for halfpence; works the screw presses for cutting out the circular pieces of copper; and coins both the faces and edges of the money at the same time: and since the circulation of the new halfpence, we are all acquainted with the superior excellence of the workmanship. By this machinery, four boys of ten or twelve years old, are capable of striking 30,000 guineas in an hour, and the machine itself keeps an unerring account of the number of pieces struck.

Emma. And I have seen the cyder-press in Kent, which consists of the same kind of machine.

Father. It would, my dear, be an almost endless task, were we to attempt to enumerate all the purposes to which the screw is applied in the mechanical arts of life; it will, perhaps, be sufficient to tell you that wherever great pressure is required, there the power of the screw is uniformly employed.

ASTRONOMY.

CONVERSATION XXII.

OF THE FIXED STARS.

TUTOR—CHARLES—JAMES.

CHARLES. The delay occasioned by our unusually long walk, has afforded us one of the most brilliant views of the heavens that I ever saw.

James. It is uncommonly clear, and the longer I keep my eyes fixed upwards, the more stars seem to appear: how is it possible to number these stars? and yet I have heard that they are numbered, and even arranged in catalogues according to their apparent magnitudes. Pray, sir, explain to us how this business was performed.

Tutor. This I will do, with great pleasure, some time hence, but at present, I must tell you that in viewing the heavens with the naked eye, we are very much deceived as to the supposed number of stars that are at any time visible. It is generally admitted, and on good authority too, that there are never more than one thousand stars

visible to the sight, unassisted by glasses, at any one time, and in one place.

James. What! can I see no more than a thousand stars if I look all around the heavens? I should suppose there were millions.

Tutor. This number is certainly the limit of what you can at present behold; and that which leads you, and persons in general, to conjecture that the number is so much larger, is owing to an optical deception.

James. Are we frequently liable to be deceived by our senses?

Tutor. We are, if we depend on them *singly*; but where we have an opportunity of calling in the assistance of one sense to the aid of another, we are seldom subject to this inconvenience.

Charles. Do you not know if you place a small marble in the palm of the left hand, and then cross the second finger of the right hand over the first, and in that position, with your eyes shut, move the marble with those parts of the two fingers at once, which are not accustomed to come into contact with any object at the same time, that the one marble will appear to the touch as two? In this instance, without the assistance of our eyes, we should be deceived by the sense of feeling.

Tutor. This is to the point, and shows that the judgment formed by means of a single sense is not always to be depended upon.

James. I recollect the experiment very well,

we had it from papa, a great while ago. But that has nothing to do with the false judgment which we are said to form about the number of stars.

Tutor. You are right; it does not immediately concern the subject before us, but it may be useful as affording a lesson of modesty, by instructing us that we ought not to close our minds against new evidence that may be offered upon any topic, notwithstanding the opinions we may have already formed. You say, that you see millions of stars, whereas the ablest astronomers assert, that with the naked eye you cannot at one time see so many as a thousand.

Charles. I should indeed have thought with my brother, had you not asserted the contrary; and I am anxious to know how the deception happens, for I am sure there must be a great deception somewhere, if I do not at this time behold very many thousands of stars in the heavens.

Tutor. You know that we see objects only by means of the rays of light which proceed from them in every direction. And you must for the present, give me credit when I tell you that the distance of the fixed stars from us is immensely great, consequently the rays of light have to travel this distance, in the course of which, especially in their passage through our atmosphere, they are subject to numberless *reflections*,

and *refractions*. By means of these, other rays of light come to the eye, every one of which, perhaps, impresses upon the mind the idea of so many separate stars. Hence arises that optical fallacy by which we are led to believe the stars which we behold are innumerable.

James. I should like to see an experiment to confirm this.

Tutor. I have no objection: in every case you ought to require the best evidence that the subject will admit of;

> To ask or search I blame thee not, for heaven
> Is as the book of God before thee set,
> Wherein to read his wond'rous works, and learn
> His seasons, hours, or days, or months, or years.
>
> MILTON.

I will show you two experiments which will go a good way to remove the difficulty. But, for this purpose, we must step into the house.

Here are two common looking-glasses, which, philosophically speaking, are *plain mirrors*. I place them in such a manner on the table that they support one another from falling by meeting at the top. I now place this half-crown between them, on a book, to raise it a little above the table. Tell me how many pieces of money you would suppose there were, if you did not know that I had used but one.

James. There are several in the glasses.

Tutor. I will alter the position of the glasses

a little, by making them almost parallel to one another: now look into them, and say what you see.

James. There are more half-crowns now than there were before.

Tutor. It is evident, then, that by *reflection* only, a single object, for I have made use of but one half-crown, will give you the idea of a vast number.

Charles. If a little contrivance had been used to conceal the method of making the experiment, I should not have believed but that there had been several half-crowns instead of one.

Tutor. Bring me your multiplying glass; look through it at the candle: how many do you see? or rather how many candles should you suppose there were, did you not know that there was but one on the table?

James. A great many, and a pretty sight it is.

Charles. Let me see; yes, there are: but I can easily count them; there are sixteen.

Tutor. There will be just as many images of the candle, or any other object at which you look, as there are different surfaces on your glass. For by the principle of *refraction*, the image of the candle is seen in as many different places as the glass has surfaees; consequently, if instead of 16 there had been 60, or, if they could have been cut and polished so small, 600, then the single candle would have given you the idea

of 60, or 600. What think you now about the stars?

James. Since I have seen that *reflection* and *refraction* will each, singly, afford such optical deceptions, I can no longer doubt, but that, if both these causes are combined as you say they are with respect to the rays of light coming from the fixed stars, a thousand real luminaries may have the power of exciting in my mind the idea of millions.

Tutor. I will mention another experiment, for which you may be prepared against the next clear star-light night. Get a long narrow tube, the longer and narrower the better, provided its weight does not render it unmanageable: examine through it any one of the largest fixed stars; which are called stars of the *first* magnitude, and you will find that though the tube takes in as much sky as would contain many such stars, yet that the single one at which you are looking, is scarcely visible, by the few rays which come *directly* from it: this is another proof that the brilliancy of the heavens is much more owing to *reflected* and *refracted* light, than to the direct rays flowing from the stars.

CONVERSATION XXIII.

Of the Fixed Stars.

Charles. Another beautiful evening presents itself; shall we take the advantage which it offers of going on with our astronomical lectures?

Tutor. I have no objection, for we do not always enjoy such opportunities as the brightness of the present evening affords.

James. I wish very much to know how to distinguish the stars, and to be able to call them by their proper names.

Tutor. This you may very soon learn; a few evenings, well improved, will enable you to distinguish all the stars of the first magnitude which are visible, and all the relative positions of the different constellations.

James. What are constellations, sir?

Tutor. The ancients, that they might the better distinguish and describe the stars, with regard to their situation in the heavens, divided them into constellations, that is, systems consisting of such stars as were near to each other, giving them the names of such men or things, as they fancied the space which they occupied in the heavens represented.

Charles. Is it then perfectly arbitrary, that

one collection is called the *great bear*, another *the dragon*; a third *Hercules*, and so on?

Tutor. It is; and though there have been additions to the number of stars in each constellation, and various new constellations invented by modern astronomers, yet the original division of the stars into these collections, was one of those few arbitrary inventions which has descended without alteration, otherwise than by addition, from the days of Ptolemy down to the present time.—Do you know how to find the four Cardinal points, as they are usually called, the North, South, West, and East?

James. O yes, I know that if I look at the sun at twelve o'clock at noon, I am also looking to the south where he then is; my back is towards the north; the west is on my right hand, and the east on my left.

Tutor. But you must learn to find these points without the assistance of the sun, if you wish to be a young astronomer.

Charles. I have often heard of the *north pole star*; that will perhaps answer the purpose of the sun, when he has left us.

Tutor. You are right; do you see those seven stars which are in the constellation of the *Great Bear?* some people have supposed their position will aptly represent a *plough*; others say, that they are more like a *wagon and horses*;—the four stars representing the body of the wagon, and the other three the horses, and hence they

are called by some the plough, and by others they are called Charles's wain or wagon. Here is a drawing of it: (Plate v. Fig. 1.) *a b d g* represents the four stars, *e z* B the other three.

Charles. What is the star P?

Tutor. That represents the polar star to which you just now alluded; and you observe, that if a line were drawn through the stars *b* and *a*, and produced far enough, it would nearly touch it.

James. Let me look in the heavens for it by this guide. There it is, I suppose; it shines with a steady, and rather dead kind of light, and it appears to me, that it would be a little to the right of the line passing through the stars *b* and *a*.

Tutor. It would, and these stars are generally known by the name of the *pointers*, because they point to *p*, the north pole, which is situated a little more than two degrees from the star P.

Charles. Is that star always in the same part of the heavens?

Tutor. It may be considered as uniformly maintaining its position, while the other stars seem to move round it as a centre. We shall have occasion to refer to this star again; at present, I have directed your attention to it, as a proper method of finding the Cardinal points by star-light.

James. Yes, I understand now, that if I look to the north, by standing with my face to that

star, the south is at my back, on my right hand is the east, and the west on my left.

Tutor. This is one important step in our astronomical studies; but we can make use of these stars as a kind of standard, in order to discover the names and positions of others in the heavens.

Charles. In what way must we proceed in this business.

Tutor. I will give you an example or two: conceive a line drawn from the star *z*, leaving B a little to the left, and it will pass through that very brilliant star A, near the horizon towards the west.

James. I see the star, but how am I to know its name?

Tutor. Look on the celestial globe for the star *z*, and suppose the line drawn on the globe, as we conceived it done in the heavens, and you will find the star, and its name.

Charles. Here it is;—its name is Arcturus.

Tutor. Take the figure, (Fig. 1.) and place Arcturus at A, which is its relative position, in respect to the constellation of the Great Bear. Now, if you conceive a line drawn through the stars *g* and *b*, and extended a good way to the right, it will pass just above another very brilliant star. Examine the globe as before, and find its name.

Charles. It is *Capella*, the *goat*.

Tutor. Now, whenever you see any of these

stars, you will know where to look for the others without hesitation.

James. But do they never move from their places?

Tutor. With respect to us, they seem to move together with the whole heavens. But they always remain in the same relative position, with respect to each other. Hence, they are called *fixed* stars, in opposition to the *planets*, which, like our earth, are continually changing their places, both with regard to the fixed stars, and to themselves also.

Charles. I now understand pretty well the method of acquiring a knowledge of the names and places of the stars.

Tutor. And with this, we will put an end to our present conversation.

CONVERSATION XXIV.

Of the Fixed Stars, and Ecliptic.

Tutor. I dare say that you will have no difficulty in finding the north polar star as soon as we go into the open air.

James. I shall at once know where to look for that and the other stars which you pointed out last night, if they have not changed their places.

Tutor. They always keep the same position, with respect to each other, though their situation, with regard to the heavens, will be different at different seasons of the year, and in different hours of the night. Let us go into the garden.

Charles. The stars are all in the same place as we left them last evening. Now, sir, if we conceive a straight line drawn through the two stars in the plough, which, in your figure (Fig. 1.) are marked *d* and *g*, and to extend a good way down, it will pass, or nearly pass through a very bright star, though not so bright as *Arcturus* or *Capella*, what is that called?

Tutor. It is a star of the second magnitude, and if you refer to the celestial globe, in the same way as you were instructed last night, you will find it is called *Regulus*, or *Cor Leonis*, the *Lion's heart.* By this method you may quickly discover the names of all the principal stars, and afterwards, with a little patience, you will easily distinguish the others, which are less conspicuous.

Charles. But they have not all names; how are they specified?

Tutor. If you look on the globe, you will observe, that they are distinguished by the differ-

ent letters of the Greek alphabet; and in those constellations, in which there are stars of different apparent magnitudes, the largest is α alpha, the next in size is β beta, the third γ gamma, the fourth δ delta, and so on.

James. Is there any particular reason for this?

Tutor. The adoption of the characters of the Greek alphabet, rather than any other, was perfectly arbitrary; it is, however, of great importance, that the same characters should be used in general by astronomers of all countries, for by this means the science is in possession of a sort of universal language.

Charles. Will you explain how this is?

Tutor. Suppose an astronomer in North America, Asia, or any other part of the earth, observe a comet in that part of the heavens where the constellation of the *plough* is situated, and he wishes to describe it to his friend in Great Britain, in order that he may know, whether it was seen by the inhabitants of this island. For this purpose, he has only to mention the time when he discovered it; its position, as nearest to some one of the stars, calling it by the Greek letter by which it is designated; and the course which it took from one star towards another. Thus he might say, that at such a time he saw a comet near δ in the Great Bear, and that its course was directed from δ to β, or any other, as it happens.

Charles. Then, if his friend here had seen a comet at the same time, he would, by this means know, whether it was the same or a different comet?

Tutor. Certainly, and hence you perceive of what importance it is, that astronomers in different countries should agree to mark the same stars and systems of stars by the same characters. But to return to that star, to which you just called my attention, the *cor leonis*, it is not only a remarkable star, but its position is also remarkable, it is situated in the *ecliptic.*

James. What is that, sir?

Tutor. The *ecliptic* is an imaginary great circle in the heavens, which the sun *appears* to describe in the course of a year. If you look on the celestial globe, you will see it marked with a *red* line, perhaps an emblem of the fierce heat communicated to us by that body.

James. But the sun seems to have a circular motion in the heavens every day.

Tutor. It does; and this is called its apparent *diurnal,* or daily motion, which is very different from the path which it appears to traverse in the course of a year. The *former* is observed by the most inattentive spectator, who cannot but know, that the sun is seen every morning in the east, at noon in the south, and in the evening in the west; but the knowledge of the *latter* must be the result of patient observation.

Charles. And what is the *green* line which crosses it?

Tutor. It is called the *Equator;* this is an imaginary circle belonging to the earth, which you must take for granted, a little longer, is of a globular form. If you can conceive the plane of the terrestrial equator to be produced to the sphere of the fixed stars, it would mark out a circle in the heavens, called the *celestial equator* or *equinoctial*, which would cut the *ecliptic* in two parts.

James. Can we trace the circle of the *ecliptic* in the heavens?

Tutor. It may be done with tolerable accuracy by two methods; *first*, by observing several remarkable fixed stars, to which the moon in its course seems to approach. The *second* method is by observing the places of the planets.

Charles. Is the moon then always in the ecliptic?

Tutor. Not exactly so; but it is always either in the ecliptic, or within five degrees and a third of it on one side or the other. The planets also, by which I mean, Mercury, Venus, Mars, Jupiter, Saturn, and the Herschel, are never more than eight degrees distant from the line of the ecliptic.

James. How can we trace this line, by help of the fixed stars?

Tutor. By comparing the stars in the heavens, with their representatives on the artificial

globe, a practice which may be easily acquired, as you have seen. I will mention to you the names of those stars, and you may first find them on the globe, and then refer to as many of them as are now visible in the heavens. The first is in the *Ram's* horn called *α Arietis*, about ten degrees to the *north* of the ecliptic; the second is the *star Aldebaran* in the Bull's eye, six degrees *south* of the ecliptic.

Charles. Then if at any time I see these two stars, I know that the ecliptic runs between them, and nearer to Aldebaran, than to that in the Ram's horn.

Tutor. Yes; now carry your eye eastward to a distance somewhat greater from Aldebaran, than that is east of α Arietis, and you will perceive two bright stars at a small distance from one another called *Castor* and *Pollux*; the lower one, and that which is least brilliant, is Pollux, seven degrees on the north side of the ecliptic. Following the same track, you will come to *Regulus*, or the *cor leonis*, which I have already observed is exactly in the line of the ecliptic. Beyond this, and only two degrees south of that line, you will find the beautiful star in the virgin's hand, called *Spica Virginis*. You then arrive at *Antares*, or the *Scorpion's heart*, five degrees on the same side of the ecliptic. Afterwards you will find *α Aquilæ*, which is situated nearly thirty degrees north of the ecliptic; and farther on is the star *Fomahant* in the fish's

mouth, about as many degrees south of that line. The ninth and last of these stars is *Pegasus*, in the wing of the flying-horse, which is north of the ecliptic nearly twenty degrees.

James. Upon what account are these nine stars particularly noticed?

Tutor. They are selected as the most conspicuous stars near the moon's orbit, and are considered as proper stations, from which the moon's distance is calculated for every three hours of time: and hence are constructed those tables in the *Nautical Almanac*, by means of which navigators, in their most distant voyages, are enabled to estimate, on the trackless ocean, the particular part of the globe on which they are.

Charles. What do you mean by the Nautical Almanac?

Tutor. It is a kind of National Almanac, intended chiefly for the use of persons traversing the mighty ocean. It was begun in the year 1767, by Dr. Maskelyne, the Astronomer Royal, and is published by anticipation for several years beforehand, for the convenience of ships going out upon long voyages. This work has been found eminently important in the course of the late voyages round the world for making discoveries.

CONVERSATION XXV.

Of the Ephemeris.

Charles. Your second method of tracing the ecliptic, was by means of the position of the planets; will you explain that now?

Tutor. I will; and to render you perfectly qualified for observing the stars, I will devote the present conversation to the purpose of explaining the use of White's Ephemeris, a little book which is published annually, and which is a necessary companion to every young astronomer.

James. Must we understand all this to study the stars?

Tutor. You must; or some other book of the same kind, if you would proceed on the best and most rational plan. Besides, when you know the use of this book, which you will completely with half an hour's attention, you have nothing more to do in order to find the position of the planets at any day of the year, than to turn to that day in the Ephemeris, and you will instantly be directed to those parts of the heavens in which the different planets are situated. Turn to the second page.

Charles. Here the astronomical characters are explained.

Tutor. The first twelve are the representatives of the signs into which the circle of the ecliptic is divided, called also the twelve signs of the *Zodiac.*

♈ Aries.	♌ Leo.	♐ Sagittarius.
♉ Taurus.	♍ Virgo.	♑ Capricorn.
♊ Gemini.	♎ Libra.	♒ Aquarius.
♋ Cancer.	♏ Scorpio.	♓ Pisces.

Every circle connected with this subject is supposed to be divided into 360 parts, called degrees, and since that of the ecliptic is also divided into 12 signs, each sign must contain 30 degrees. Astronomers sub-divide each degree into minutes and seconds, thus if I would express an angle of 25 degrees, 11 minutes, and 45 seconds, I should write 25°.. 11′.. 45″. Or, if I would express the situation of the sun for the 1st of January, 1800, I look into the Ephemeris and find it in Capricorn, or ♑ 10°.. 56′.. 38″.

James. What do you mean by the Zodiac?

Tutor. It is an imaginary broad circle or belt surrounding the heavens, about sixteen degrees wide; along the middle of which runs the ecliptic. The term Zodiac is derived from a Greek word signifying an animal, because each of the twelve signs formerly represented some animal; that which we now call Libra, being by the ancients reckoned a part of Scorpio.

James. Why are the signs of the Zodiac called by the several names of Aries, Taurus, Leo, &c.? I see no likeness in the heavens to Rams, or Bulls, or Lions, which are the English words for those Latin ones.

Tutor. Nor do I; nevertheless, the ancients saw, by the help of a strong imagination, a similarity between those animals, and the places which certain systems of stars took up in the heavens, and gave them the names which have continued to this day.

Charles. Perhaps these were originally invented, in the same way as we sometimes figure to our imagination, the appearances of men, beasts, ships, trees, &c. in the flying clouds or in the fire.

Tutor. They might possibly have no better authority for their origin. At any rate it will be useful for you to have the names of the twelve signs in your memory, as well as the order in which they stand: I will therefore repeat some lines written by Dr. Watts, in which they are expressed in English, and will be easily remembered:

> The *Ram*, the *Bull*, the *heavenly Twins*,
> And next the *Crab*, the *Lion* shines,
>   The *Virgin*, and the *Scales*;
> The *Scorpion*, *Archer*, and Sea-*Goat*,
> The *Man* that holds the *watering-pot*,
>   And *Fish* with glittering tails.

Charles. We come now to the characters placed before the planets.

Tutor. These, like the former, are but a kind of short-hand characters, which it is esteemed easier to write, than the names of the planets at length. They are as follow:

♅ The Herschel.	☉ The Sun.
♄ Saturn.	♀ Venus.
♃ Jupiter.	☿ Mercury.
♂ Mars.	☽ The Moon.
⊕ The Earth.	

With the other characters you have no need to trouble yourselves, till you come to calculate eclipses, and construct astronomical tables, a labour which may be deferred for some years to come. Turn to the eighth page of the Ephemeris.

James. Have we no concern with the intermediate pages between the second and eighth?

Tutor. They do not contain any thing that requires explanation. In the eighth page, after the common almanac for January, the first two columns point out the exact time of the sun's rising and setting at London; thus on the 10th day of January he rises at 58 minutes after 7 in the morning, and sets at 2 minutes past 4 in the afternoon. The third column gives the *declination* of the sun.

James. What is that, sir?

Tutor. The *declination* of the sun, or of any heavenly body, is its distance from the imaginary circle in the heavens, called the *equinoctial*. Thus you observe that the sun's declination on the 1st of January is 23°.. 4′ south; or, it is so many degrees south of the imaginary *equator*. Turn to March, 1803, and you will see that between the 20th and 21st days it is in the equator, for at 12 o'clock at noon on the 20th it is only 25′ south, and at the same hour on the 21st it is 1′ north of that line: and when it is in the equator, then it has no declination.

Charles. Do astronomers always reckon from 12 o'clock at noon?

Tutor. They do: and hence the astronomical day begins 12 hours *later* than the day according to common reckoning: and therefore the declination, longitude, latitude, &c. of the sun, moon, and planets, are always put down for 12 o'clock, at noon of the day to which they are opposite. Thus the sun's declination for the 16th of January at 12 o'clock is 20°.. 56′ south.

Charles. Is that because it is the commencement of the astronomical day, though in common life it be called 12 o'clock?

Tutor. It is. The three next columns contain the moon's declination, the time of her rising and setting, and the time of her *southing*, or when she comes to the meridian or south part of the heavens.

Charles. Does she not come to the south at noon as well as the sun?

Tutor. No; the moon never comes to the meridian at the same time as the sun, but at the time of *new* moon. And this circumstance takes place at every new moon, as you may see by casting your eye down the several columns in the Ephemeris which relate to the moon's southing.

The glory, the changes, and the motion of the moon, are beautifully described in the following lines:

By thy command the Moon, as day-light fades,
Lifts her broad circle in the deep'ning shades;
Array'd in glory, and enthron'd in light,
She breaks the solemn terrors of the night;
Sweetly inconstant in her varying flame,
She changes still, another, yet the same!
Now in decrease, by slow degrees she shrouds
Her fading lustre in a veil of clouds;
Now of increase, her gath'ring beams display
A blaze of light, and give a paler day;
Ten thousand stars adorn her glitt'ring train,
Fall when she falls, and rise with her again;
And o'er the deserts of the sky unfold
Their burning spangles of sidereal gold;
Through the wide heav'ns she moves serenely bright,
Queen of the gay attendants of the night;
Orb above orb in sweet confusion lies,
And with a bright disorder paints the skies.

BROOME.

James. What do you say of the 7th column:—*the clock before the sun?*

Tutor. A full explanation of that must be deferred till we come to speak of the *equation of time;* at present it will be sufficient for you to know that if you are in possession of a very accurate and well regulated clock, and also of an excellent sun-dial, they will be together only four days in a year; now this 7th column in the Ephemeris points out how much the clock is before the sun; or the sun before the clock for every day in the year. On *twelfth-day*, 1809, for instance, the clock is faster than the sun by six minutes and twelve seconds: but if you turn to *May-day* you will find that the clock is 3'..4" slower than the sun.

James. What are the four days in the year, when the clock and dial are together?

Tutor. About the 15th of April; the 15th of June; the 1st of September; and Christmas-day.

Charles. By this table then we may regulate our clocks and watches.

James. In what manner?

Charles. Examine on any particular day the clock or watch and dial, at the same time, say 12 o'clock, and observe whether the difference between them answers to the difference set down in the table, opposite to the day of observation. Thus on the 12th of March, 1809, the clock will not show true time unless it be 10'..3" before the dial, or when the dial is 12 o'clock it must be 10'..3" past 12 by the clock or watch.

Tutor. Well, let us proceed to the next page. The first three *short* columns, relating only to the duration of day-light and twilight, require no explanation: the fourth we shall pass over for the present; and the remaining five give the *latitude* of the planets.

James. What do you mean by the latitude, sir?

Tutor. The latitude of any heavenly body is its distance from the *ecliptic* north or south. The latitude of *Venus*, on new-year's day, 1803, is 4° north.

Charles. Then the *latitude* of heavenly bodies, has the same reference to the *ecliptic*, that *declination* has to the *equator?*

Tutor. It has.

James. But I do not see any table of the sun's latitude.

Tutor. I dare say your brother can give you a reason for this.

Charles. Since the latitude of a heavenly body is its *distance from* the ecliptic, and since the sun is always in the ecliptic, therefore he can have no latitude.

Tutor. The *longitude* of the sun and planets is the only thing in this page that remains to be explained. The longitude of a heavenly body is its distance from the first point of the sign Aries, and it is measured on the ecliptic. It is usual, however, as you observe in the Ephemeris, to express the longitude of a heavenly body by the

degree of the sign in which it is. In this way the sun's longitude on the 1st of January, 1809, is in Capricorn 10°. .45'. .14"; that of the moon in Cancer 6°. .4'; that of Jupiter is in Pisces, 13°. .35'.

Charles. There are some short columns at the bottom of the former page that you have omitted.

Tutor. The use of these will be better understood when we come to converse respecting the planets.*

CONVERSATION XXVI.

Of the Solar System.

Tutor. We will now proceed to the description of the *Solar System.*

James. Of what does that consist, sir?

Tutor. It consists of the sun, and planets, with their satellites or moons. It is called the *Solar System,* from *Sol* the sun, because the sun is supposed to be fixed in the centre, while the

* For the explanation of Heliocentric Longitude, see Conversation XLI.

planets, and our earth among them, revolve round him at different distances.

Charles. But are there not some people who believe that the sun goes round the earth?

Tutor. Yes, it is an opinion embraced by the generality of persons, not accustomed to reason on these subjects. It was adopted by Ptolemy, who supposed the earth perfectly at rest, and the sun, planets, and fixed stars to revolve about it every twenty-four hours.

James. And is not that the most natural supposition?

Tutor. If the sun and stars were small bodies in comparison of the earth, and were situated at no very great distance from it, then the system maintained by Ptolemy and his followers might appear the most probable.

James. Are the sun and stars very large bodies then?

Tutor. The sun is more than a million of times larger than the earth which we inhabit, and many of the fixed stars are probably much larger than he is.

Charles. What is the reason, then, that they appear so small?

Tutor. This appearance is caused by the immense distance there is between us and these bodies. It is known with certainty, that the sun is more than 95 millions of miles distant from the earth, and the nearest fixed star is pro-

bably more than two hundred thousand times farther from us than even the sun himself.*

Charles. But we can form no conception of such distances.

Tutor. We talk of millions, with as much ease as of hundreds or tens, but it is not, perhaps, possible for the mind to form any adequate conceptions of such high numbers. Several methods have been adopted to assist the mind in comprehending the vastness of these distances. You have some idea of the swiftness with which a cannon-ball proceeds from the mouth of the gun?

James. I have heard at the rate of eight miles in a minute.

Tutor. And you know how many minutes there are in a year?

James. I can easily find that out, by multiplying 365 days by 24 for the number of hours, and that product by 60, and I shall have the number of minutes in a year, which number is 525,600.

Tutor. Now if you divide the distance of the sun from the earth by the number of minutes in a year multiplied by 8, because the cannon-ball travels at the rate of 8 miles in one minute, and

* The young reader will, when he is able to manage the subject, see this clearly demonstrated by a series of propositions in the 5th book of Dr. Enfield's Institutes of Natural Philosophy. Second Edition. See p. 346 to end of book V.

you will know how long any body issuing from the sun, with the velocity of a cannon ball, would employ in reaching the earth.

Charles. If I divide 95,000,000 by 525,600 multiplied by 8, or 4,204,800, the answer will be more than 22, the number of years taken for the journey.

Tutor. Is it then probable that bodies so large, and at such distances from the earth, should revolve round it every day?

Charles. I do not think it is.—Will you, sir, go on with the description of the *Solar System?*

Tutor. According to this system, the sun is in the centre, about which the planets revolve from *west* to *east*, according to the order of the signs in the ecliptic; that is, if a planet is seen in Aries, it advances to Taurus, then to Gemini, and so on.

James. How many planets are there belonging to the sun?

Tutor. There are seven, besides some smaller bodies of the same kind discovered within these nine years. C (Plate v. Fig. 2.) represents the sun, the nearest to which *Mercury* revolves in the circle *a;* next to him is the beautiful planet *Venus*, who performs her revolution in the circle *b;* then comes the *Earth* in *t;* next to which is *Mars* in *e;* then *Jupiter* in the circle *f;* afterwards *Saturn* in *g;* and far beyond him the *Herschel* planet performs his revolution in the

circle *h*. Do you recollect the lines in Thomson's Summer?

> ——and thou, O Sun;
> Soul of surrounding worlds! in whom best seen
> Shines out thy MAKER! may I sing of thee?
> 'Tis by thy secret, strong attractive force,
> As with a chain indissoluble bound,
> Thy system rolls entire: from the far bourne
> Of utmost *Herschel*, wheeling wide his round
> Of *fourscore* years; to Mercury, whose disk
> Can scarce be caught by philosophic eye,
> Lost in the near effulgence of thy blaze.

Charles. You have substituted the words Herschel, and fourscore, for Saturn and thirty. These lines are descriptive of the figure.

James. For what are the smaller circles which are attached to several of the larger ones intended?

Tutor. They are intended to represent the *orbits* of the several satellites or moons belonging to some of the planets.

James. What do you mean by the word orbit?

Tutor. The path described by a planet in its course round the sun, or by a moon round its primary planet, is called its *orbit*. Look to the orbit of the earth in *t* (Fig. 2.) and you will see a little circle which represents the orbit in which our moon performs its monthly journey.

Charles. Has neither *Mercury* nor *Venus* any moon?

Tutor. None have ever been discovered belonging either to Mercury, Venus, or Mars. Jupiter, as you observe by the figure, has four moons: Saturn has seven: and the Herschel (which also goes by the name of the Georgium Sidus) has six; these for want of room are not drawn in the plate.

Charles. The *Solar System* then consists of the sun as the centre, round which revolves *seven* planets, and *eighteen* satellites or moons. Are there no other bodies belonging to it?

Tutor. Yes, as I just observed, four other planetary bodies have been very lately discovered as belonging to the solar system. These are very small, and named from the gentlemen who discovered them, who were Messrs. Piazzi, Olbers, and Harding. They are also called the *Ceres Ferdinandea, Pallas, Juno,* and *Vesta.* There are comets also which make their appearance occasionally; and it would be wrong positively to affirm that there can be no other planets belonging to the solar system; since, besides the four bodies just mentioned, it is only within these thirty years that the seventh or the Herschel has been known to exist as a planet connected with this system.

Charles. Who first adopted the system of the world which you have been describing?

Tutor. It was conceived and taught by Pythagoras to his disciples, 500 years before the time of Christ. But it seems soon to have been

disregarded, or perhaps totally rejected, till about 300 years ago, when it was revived by Copernicus, and is at length generally adopted by men of science:

The sun revolving on his axis turns,
And with creative fire intensely burns;
Impell'd the forcive air, our earth supreme
Rolls with the planets round the solar gleam;
First Mercury completes her transient year,
Glowing refulgent, with reflected glare;
Bright Venus occupies a wider way;
The early harbinger of night and day:
More distant still our globe terraqueous turns,
Nor chills intense, nor fiercely heated burns.
Around her rolls the lunar orb of light,
Trailing her silver glories through the night:
Beyond our globe the sanguine Mars displays
A strong reflection of primeval rays;
Next belted Jupiter far distant gleams,
Scarcely enlighten'd with the solar beams:
With four unfix'd receptacles of light
He towers majestic through the spacious height;
But farther yet the tardy Saturn lags,
And seven attendant luminaries drags;
Investing with a double ring his pace,
He circles through immensity of space.

CHATTERTON.

CONVERSATION XXVII.

Of the Figure of the Earth.

Tutor. Having, in our last conversation, given you a description of the Solar System in general, we will now proceed to consider each of its parts separately; and since we are most of all concerned with the *earth*, we will begin with that body.

James. You promised to give us some reasons why this earth must be in the form of a globe and not a mere extended plane, as it appears to common observation.

Tutor. Suppose you were standing by the sea-shore, on a level with the water, and at a very considerable distance, as far as the eye can reach, you observe a ship approaching, what ought to be the appearance, supposing the surface of the sea to be a flat plane?

Charles. We should, I think, see the whole ship at once, that is, the hull would be visible as soon as the top-mast.

Tutor. It certainly must, or indeed rather sooner, because the body of the vessel being so much larger than a slender mast, it must necessarily be visible at a greater distance.

James. Yes, I can see the steeple of a church at a much greater distance than I can discern the iron conductor which is upon it, and that I can perfectly see long before the little piece of gold wire, which is fixed at its extremity, is visible.

Tutor. Well, but the top-mast of a vessel at sea is always in view some little time before the hull of the vessel can be discerned. Now, if the surface of the sea be globular, this ought to be the appearance, because the protuberance or swelling of the water between the vessel and the eye of the spectator, will hide the body of the ship some time after the pendant is seen above.

Charles. In the same way as if a high building, a church for instance, were situated on one side of a hill, and I was walking up on the opposite side, the steeple would come first in sight, and, as I advanced towards the summit, the other parts would come successively in view.

Tutor. Your illustration is quite to the purpose: in the same way two persons, walking up a hill on the opposite sides, will perceive each other's heads first; and as they advance to the top, the other parts of their bodies will become visible. With respect to the ship, the following figure will convey the idea very completely. (Plate v. Fig. 3.) Suppose C A B represent a small part of the curved surface of the sea: if a spectator stand at B, while a ship is at C,

only a small part of the mast is visible to him, but as it advances, more of the ship is seen, till it arrive at *e*, when the whole will be in sight:

> Behold, when the glad ship shoots from the port
> Upon full sail, the hulk first disappears,
> And then the lower, then the higher sails;
> At length the summit of the towering mast
> Alone is seen: nor less, when from the ship
> The longing sailor's eye, in hope of shore:
> For then, from the top mast, tho' more remote
> Than either deck, the shore is first beheld.
>
> LOFFT'S EUDOSIA.

Charles. When I stood by the sea-side the water did *not* appear to me to be curved.

Tutor. Perhaps not; but its convexity may be discovered upon any still water; as upon a river, which is extended a mile or two in length, for you might see a very small boat at that distance while standing upright; if then you stoop down so as to bring your eye near the water, you will find the surface of it rising in such a manner as to cover the boat, and intercept its view completely. Another proof of the globular figure of the earth is, that it is necessary for those who are employed in cutting canals, to make a certain allowance for the convexity; since the true level is not a straight line, but a curve which falls below it eight inches every mile.

Charles. I have heard of people sailing round the world, which is another proof, I imagine, of the globular figure of the earth.

Tutor. It is a well known fact that navigators have set out from a particular port, and by steering their course continually westward, have at length arrived at the same place from whence they first departed. Now had the earth been an extended plane, the longer they had travelled, the farther must they have been from home.

Charles. How is it known that they continued the same course? might they not have been driven round at open sea?

Tutor. By means of the mariner's compass, the history, property, and uses of which, I will explain very particularly in a future part of our lectures, the method of sailing on the ocean by one certain track, is as sure as travelling on the high London road from the metropolis of York. By this method, Ferdinand Magellan sailed in the year 1519 from the western coast of Spain, and continued his voyage in a westward course till he arrived after 1124 days in the same port from whence he set out. The same with respect to Great Britain, was done by our own countrymen Sir Francis Drake, Lord Anson, Captain Cook, and many others.

Charles. Is then the common terrestrial globe a just representation of the earth?

Tutor. It is, with this small difference,* that

* What the earth loses of its sphericity, by mountains and valleys, is very inconsiderable: the highest mountain bearing

the artificial globe is a perfect sphere, whereas the earth is a spheroid, that is, in the shape of an orange, the diameter from *pole* to *pole* being about 37 miles shorter than that at the *equator*.

James. What are the poles, sir?

Tutor. In the artificial globe (Plate v. Fig. 4.) there is an axis N S about which it turns; now the two extremities or ends of this axis N and S are called the poles.

> The globe terrestrial, with its slanting poles,
> And all its pond'rous load, unwearied rolls.
>
> BLACKMORE.

Charles. Is there any axis belonging to the earth?

Tutor. No; but, as we shall to-morrow show, the earth turns round once in every 24 hours, so astronomers imagine an axis upon which it revolves as upon a centre, the extremities of which imaginary axis are the poles of the earth, of these N the north pole points at all times exactly

so little proportion to its bulk, as scarcely to be equivalent to the minutest protuberance on the surface of an orange:

> These inequalities to us seem great;
> But to an eye that comprehends the whole,
> The tumour which to us so monstrous seems
> Is as a grain of sparkling sand that clings
> To the smooth surface of a sphere of glass:
> Or as a fly upon the convex dome
> Of a sublime, stupendous edifice.
>
> LOFFT.

to *p*, (Fig. 1.) the north pole of the heavens which we have already described, and which is, as you recollect, within two degrees of the polar star.

James. And how do you define the *equator?*

Tutor. The *equator* A B (Fig. 4.) is the circumference of an imaginary circle passing through the centre of the earth, perpendicular to the axis N S, and at equal distances from the poles.

Charles. And I think you told us, that if we conceived this circle extended every way to the fixed stars, it would form the *celestial equator.*

Tutor. I did: it is also called the *equinoctial,* and you must not forget, that in this case it would cut the circle of the *ecliptic* C D in two points.

James. Why is the *ecliptic* marked on the terrestrial globe, since it is a circle peculiar to the heavens?

Tutor. Though the *ecliptic* be peculiar to the heavens, and the *equator* to the earth, yet they are both drawn on the terrestrial and celestial globes, in order, among other things, to show the position which these imaginary circles have to one another.

I shall now conclude our present conversation, with observing, that besides the proofs adduced for the globular form of the earth, there are others equally conclusive, which will be better understood a few days hence.

CONVERSATION XXVIII.

Of the Diurnal Motion of the Earth.

Tutor. Well, gentlemen, are you satisfied that the earth on which you tread is a globular body and not a mere extended plane?

Charles. Admitting the facts which you mentioned yesterday, viz. that the top-mast of a ship at sea is always visible before the body of the vessel comes into sight;—that navigators have repeatedly, by keeping the same direction, sailed round the world;—and that persons employed in digging canals, can only execute their work with effect, by allowing for the supposed globular shape of the earth, it is evident the earth cannot be a mere extended plane.

James. But all these facts can be accounted for, upon the supposition that the earth is a globe, and therefore you conclude it is a globe: this was, I believe, the nature of the proof?

Tutor. It was; let us now advance one step further, and show you that this globe turns on an imaginary axis every twenty-four hours; and thereby causes the succession of day and night:

And earth self-balanc'd on her centre hung.
PAR. LOST.

James. I shall wonder if you are able to afford such satisfactory evidence of the daily motion of the earth, as of its globular form.

Tutor. I trust, nevertheless, that the arguments on this subject will be sufficiently convincing, and that before we part you will admit, that the apparent motion of the sun and stars is occasioned by the diurnal motion of the earth.

Charles. I shall be glad to hear how this can be proved; for if in the morning, I look at the sun when rising, it appears in the east, at noon it has travelled to the south, and in the evening I see it set in the western part of the heavens.

James. Yes, and we observed the same last night (March the 1st) with respect to *Arcturus*, for about eight o'clock it had just risen in the north-east part of the heavens, and when we went to bed two hours after, it had ascended a good height in the heavens, evidently travelling towards the west.

Tutor. It cannot be denied that the heavenly bodies appear to rise in the east and set in the west; but the *appearance* will be the *same* to us, whether those bodies revolve about the earth while that stands still, or they stand still while the earth turns on its axis the contrary way.

Charles. Will you explain this, sir?

Tutor. Suppose G R C B (Plate VI. Fig. 5.) to represent the earth, T the centre on which it turns from west to east, according to the order of the letters G R C B. If a spectator on the sur-

face of the earth at R, see a star at H, it will appear to him to have just risen; if now the earth be supposed to turn on its axis a fourth part of a revolution, the spectator will be carried from R to C, and the star will be just over his head; when another fourth part of the revolution is completed, the spectator will be at B, and to him the star at H will be setting, and will not be visible again till he arrive, by the rotation of the earth, at the station R.

Charles. To the spectator, then, at R, the appearance would be the same whether he turned with the earth into the situation B, or the star at H had described, in a contrary direction, the space H Z O in the same time.

Tutor. It certainly would.

James. But if the earth really turned on its axis, should we not perceive the motion.

Tutor. The earth in its diurnal rotation being subject to no impediments by resisting obstacles, its motion cannot affect the senses. In the same way ships on a smooth sea are frequently turned entirely round by the tide, without the knowledge of those persons who happen to be busy in the cabin or between the decks.

Charles. That is, because they pay no attention to any other object but the vessel in which they are. Every part of the ship moves with themselves.

James. But if while the ship is turning, with-

out their knowledge, they happen to be looking at fixed distant objects, what will be the appearance?

Tutor. To them, the objects which are at rest will appear to be turning round the contrary way. In the same manner we are deceived in the motion of the earth round its axis; for if we attend to nothing but what is connected with the earth, we cannot perceive a motion of which we partake ourselves, and if we fix our eyes on the heavenly bodies, the motion of the earth being so easy, they will appear to be turning in a direction contrary to the real motion of the earth.

Charles. I have sometimes seen a sky-lark hovering and singing over a particular field for several minutes together; now if the earth is continually in motion while the bird remains in the same part of the air, why do we not see the field, over which he first ascended, pass from under him?

Tutor. Because the atmosphere, in which the lark is suspended, is connected with the earth, partakes of its motion, and carries the lark along with it; and therefore, independently of the motion given to the bird by the exertion of its wings, it has another in common with the earth, yourself, and all things on it, and being common to us all, we have no methods of ascertaining the fact by means of the senses. The

rotation of the earth on its axis, the smoothness of its motion, and its effect on the atmosphere, are described by Milton in three lines:

> ——That spinning sleeps
> On her soft axle as she paces even,
> And bears us swift with the smooth air along.

James. Though the motion of a ship cannot be observed without objects at rest to compare with it, yet I cannot help thinking that if the earth moved, we should be able to discover it by means of the stars if they are fixed.

Tutor. Do you not remember once sailing very swiftly on the river, when you told me that you thought all the trees, houses, &c. on its banks were in motion?

James. I now recollect it well, and I had some difficulty in persuading myself that it was not so.

Charles. This brings to my mind a still stronger deception of this sort: when travelling with great speed in a post-chaise, I suddenly waked from sleep in a smooth but narrow road, and I could scarcely help thinking, for several minutes, but that the trees and hedges were running away from us, and not we from them.

Tutor. I will mention another curious instance of this kind: if you ever happen to travel pretty swiftly in a carriage by the side of a field ploughed into long narrow ridges, and perpen-

dicular to the road, you will think that all the ridges are turning round in a direction contrary to that of the carriage. These facts may satisfy you that the appearances will be precisely the same to us, whether the earth turn on its axis from west to east, or the sun and stars move from east to west.

James. They will: but which is the more natural conclusion?

Tutor. This you shall determine for yourself. If the earth (Plate v. Fig. 4.) turns on its axis in 24 hours, at what rate will any part of the equator A B move?

Charles. To determine this we must find the measure of its circumference, and then dividing this by 24 we shall get the number of miles passed through in an hour.

Tutor. Just so: now call the semi-diameter of the earth 4000 miles, which is rather more than the true measure.

James. Multiplying this by six* will give 24,000 miles for the circumference of the earth

* If the reader would be accurate in his calculations he must take the mean radius of the earth at 3965 miles, and this multiplied by 6,28311 will give 24,912 miles for the circumference. Through the remainder of this work, the decimals in multiplication are omitted in order that the mind may not be burdened with odd numbers. It seemed necessary, however, in this place to give the true semi-diameter of the earth, and the number (accurate to five places of decimals) by which if the radius of any circle be multiplied, the circumference is obtained.

at the equator, and this divided by 24, gives 1000 miles for the space passed through in an hour.

Tutor. You are right. The sun, I have already told you, is 95 millions of miles distant from the earth: tell me therefore, Charles, at what rate that body must travel to go round the earth in 24 hours?

Charles. I will; 95 millions multiplied by six will give 570 millions of miles for the length of his circuit, this divided by 24 gives nearly 24 millions of miles for the space he must travel in an hour, to go round the earth in a day.

Tutor. Which now is the more probable conclusion, either that the earth should have a diurnal motion on its axis of 1000 miles in an hour, or that the sun, which is a million of times larger than the earth, should travel 24 millions of miles in the same time?

James. It is certainly more rational to conclude that the earth turns on its axis, the effect of which you told us was the alternate succession of day and night.

Tutor. I did; and on this and some other topics we will enlarge to-morrow.

CONVERSATION XXIX.

Of Day and Night.

James. You are now, sir, to apply the rotation of the earth about its axis to the succession of day and night.

Tutor. I will; and for this purpose, suppose G R C B (Plate VI. Fig 5.) to be the earth, revolving on its axis, according to the order of the letters, that is, from G to R, R to C, &c. If the sun be fixed in the heavens at Z, and a line H O be drawn through the centre of the earth T, it will represent that circle, which when extended to the heavens is called the *rational horizon.*

Charles. In what does this differ from the *sensible horizon?*

Tutor. The *sensible horizon* is that circle in the heavens which bounds the spectator's view, and which is greater or less, according as he stands higher or lower. For example; an eye placed at *five* feet above the surface of the earth or sea, sees 2¾ miles every way: But if it be at 20 feet high, that is four times the height, it will see 5½ miles, or twice the distance.*

* See Dr. Ashworth's Trigonometry, Prop. 31. 2d Edition, 1803.

Charles. Then the *sensible* differs from the *rational* horizon in this, that the *former* is seen from the surface of the earth, and the *latter* is supposed to be viewed from its centre.

Tutor. You are right; and the rising and setting of the sun and stars are always referred to the *rational* horizon.

James. Why so? they appear to rise and set as soon as they get above, or sink below that boundary which separates the visible from the invisible part of the heavens.

Tutor. They do not, however: and the reason is this, that the distance of the sun and fixed stars is so great in comparison of 4000 miles (the difference between the surface and centre of the earth,) that it can scarcely be taken into account.

Charles. But 4000 miles seem to me an immense space.

Tutor. Considered separately, they are so, but when compared with 95 millions of miles, the distance of the sun from the earth, they almost vanish as nothing.

James. But do the rising and setting of the moon, which is at the distance of 240,000 miles only, respect also the rational horizon?

Tutor. Certainly; for 4000 compared with 240,000, bear only the proportion of 1 to 60. Now if two spaces were marked out on the earth in different directions, the one 60, and the

other 61 yards, should you at once be able to distinguish the greater from the less?

Charles. I think not.

Tutor. Just in the same manner does the distance of the centre from the surface of the earth vanish in comparison of its distance from the moon.

James. We must not, however, forget the succession of day and night.

Tutor. Well then; if the sun be supposed at Z, it will illuminate by its rays all that part of the earth that is above the horizon H O: to the inhabitants at G, its western boundary, it will appear just rising: to those situated at R, it will be noon; and to those in the eastern part of the horizon C, it will be setting.

Charles. I see clearly why it should be noon to those who live at R, because the sun is just over their heads, but it is not so evident, why the sun must appear rising and setting to those who are at G and C.

Tutor. You are satisfied that a spectator cannot, from any place, observe more than a semicircle of the heavens at any one time; now what parts of the heavens will the spectator at G observe?

James. He will see the concave hemisphere Z O N.

Tutor. The boundary to his view will be N and Z, will it not?

Charles. Yes; and consequently the sun at Z, will to him be just coming into sight.

Tutor. Then, by the rotation of the earth, the spectator at G will in a few hours come to B, when, to him, it will be noon; and those who live at B, will have descended to C; now what part of the heavens will they see in this situation?

James. The concave hemisphere N H Z, and Z, being the boundary of their view one way, the sun will to them be setting.

Tutor. Just so. After which they will be turned away from the sun, and consequently it will be night to them till they come again to G. Thus, by this simple motion of the earth on its axis, every part of it is, by turns, enlightened and warmed by the cheering beams of the sun.

Charles. Does this motion of the earth account also for the apparent motion of the fixed stars?

Tutor. It is owing to the revolution of the earth round its axis, that we imagine the whole starry firmament revolves about the earth in 24 hours.

James. If the heavens appear to turn on an axis, must there not be two points, namely, the extremities of that imaginary axis, which always keep their position?

Tutor. Yes, we must be understood to except the two celestial poles which are opposite to the poles of the earth, consequently each fixed star

appears to describe a greater or a less circle round these, according as it is more or less remote from those celestial poles.

Charles. When we turn from that hemisphere in which the sun is placed, we immediately gain sight of the other in which the stars are situated.

Tutor. Every part of the heaven is decorated with these glorious bodies: and

> Night opes the noblest scenes, and sheds an awe,
> Which gives those venerable scenes full weight,
> And deep reception in th' intender'd heart.
> This gorgeous apparatus! This display!
> This ostentation of creative power!
> This theatre! what eye can take it in?
> By what divine enchantment was it rais'd
> For minds of the first magnitude to launch
> In endless speculation, and adore?
> One sun by day, by night ten thousand shine:
> And light us deep into the Deity;
> How boundless in magnificence and might!
>
> YOUNG.

James. If every part of the heavens be thus adorned, why do we not see the stars in the day as well as the night?

Tutor. Because in the day time, the sun's rays are so powerful, as to render *those* coming from the fixed stars invisible. But if you ever happen to go down into any very deep mine, or coal-pit, where the rays of the sun cannot reach the eye, and it be a clear day, you may by looking up to the heavens, see the stars at noon as well as in the night.

Charles. If the earth always revolve on its axis in 24 hours, why does the length of the days and nights differ in different seasons of the year?

Tutor. This depends on other causes connected with the earth's *annual* journey round the sun, upon which we will converse the next time we meet.

CONVERSATION XXX.

Of the Annual Motion of the Earth.

Tutor. Besides the *diurnal* motion of the earth by which the succession of day and night is produced; it has another, called its *annual* motion, which is the journey it performs round the sun in 365 days, 5 hours, 48 minutes, and 49 seconds.

Charles. Are the different seasons to be accounted for by this motion of the earth?

Tutor. Yes, it is the cause of the different lengths of the days and nights, and consequently of the different seasons, viz. *Spring*, *Summer*, *Autumn*, and *Winter*:

It shifts the seasons, months, and days,
The short-liv'd offspring of revolving time;
By turns they die, by turns are born.
Now cheerful Spring the circle leads
And strews with flow'rs the smiling meads;
Gay Summer next, whom russet robes adorn,
And waving fields of yellow corn;
Then Autumn, who with lavish stores the lap of Nature spreads;
Decrepit Winter, laggard in the dance
(Like feeble age opprest with pain,)
A heavy season does maintain,
With driving snows and winds and rain;
Till Spring recruited to advance,
The various year rolls round again.

HUGHES.

James. How is it known that the earth makes this annual journey round the sun?

Tutor. I told you yesterday, that through the shaft of a very deep mine, the stars are visible in the day as well as in the night; they are also visible in the day time, by means of a telescope properly fitted up for the purpose; by this method, the sun and stars are visible at the same time. Now if the sun be seen in a line with a fixed star, to-day at any particular hour, it will, in a few weeks, by the motion of the earth, be found considerably to the east of him: and if the observations be continued through the year, we shall be able to trace him round the heavens to the same fixed star from which we set out; consequently, the sun must have made a journey round the earth in that time; or the earth round him.

Charles. And the sun being a million of times larger than the earth, you will say that it is more natural, that the smaller body should go round the larger, than the reverse.

Tutor. That is a proper argument; but it may be stated in a much stronger manner. The sun and earth mutually attract one another, and since they are in equilibrio by this attraction, you know, their momenta must be equal,* therefore the earth being the smaller body, must make out by its motion what it wants in the quantity of its matter, and, of course, it must be that which performs the journey.

James. But if you refer to the principle of the lever, to explain the mutual attraction of the sun and earth, it is evident that both bodies must turn round some point as a common centre.

Tutor. They do; and that is the common centre of gravity of the two bodies. Now this point between the earth and sun is within the surface of the latter body.

Charles. I understand how this is; because the centre of gravity between any two bodies, must be as much nearer to the centre of the larger body than the smaller, as the former contains a greater quantity of matter than the latter.

Tutor. You are right: but you will not conclude that, because the sun is a million of times

* See Conversation XIV. p. 73.

larger than the earth, therefore it contains a quantity of matter, a million of times greater than that contained in the earth.

James. Is it then known, that the earth is composed of matter more dense than that which composes the body of the sun?

Tutor. The earth is composed of matter four times denser than that of the sun; and hence the quantity of matter in the sun is between two and three hundred thousand times greater than that which is contained in the earth.

Charles. Then for the momenta of these two bodies to be equal, the velocity of the earth must be between two and three hundred thousand times greater than that of the sun.

Tutor. It must: and to effect this, the centre of gravity between the sun and earth, must be as much nearer to the centre of the sun, than it is to the centre of the earth, as the former body contains a greater quantity of matter than the latter: and hence it is found to be several thousand miles within the surface of the sun.

James. I now clearly perceive, that since one of these bodies revolves about the other in the space of a year, and that they both move round their common centre of gravity, that it must, of necessity, be the earth which revolves about the sun, and not the sun round the earth.

Tutor. Your inference is just. To suppose that the sun moves round the earth, is as absurd as to maintain, that a mill-stone could be made to move round a pebble.

CONVERSATION XXXI.

Of the Seasons.

Tutor. I will now show you how the different seasons are produced by the annual motion of the earth.

James. Upon what do they depend, sir?

Tutor. The variety of the seasons depends (1,) upon the length of the days and nights; and (2,) upon the position of the earth with respect to the sun.

Charles. But if the earth turn round its imaginary axis every 24 hours, ought it not to enjoy equal days and nights all the year?

Tutor. This would be the case if the axis of the earth N S (Plate VI. Fig. 6.) were perpendicular to a line C E drawn through the centres of the sun and earth; for then as the sun always enlightens one half of the earth by its rays, and as it is day at any given place on the globe, so long as that place continues in the enlightened hemisphere, every part, except the two poles, must, during its rotation on its axis, be one half of its time in the light and the other half in darkness: or, in other words, the days and nights would be equal to all the inhabitants of the earth, excepting to those, if any, who live at the poles.

James. Why do you except the people at the poles?

Tutor. Because the view of the spectator situated at the poles N and S, must be bounded by the line C, E, consequently to him the sun would never appear to rise, or set, but always be in the horizon.

Charles. If the earth were thus situated, would the rays of the sun always fall vertically to the same part of it?

Tutor. They would: and that part would be E Q the equator; and, as we shall presently show, the heat excited by the sun being greater or less in proportion as its rays come more or less perpendicularly upon any body, the parts of the earth about the equator would be scorched up, while those beyond forty or fifty degrees on each side of that line and the poles, would be desolated by an unceasing winter:

———————Some say the sun
Was bid turn reins from th' *equinoctial* road
Up to the *Tropic Crab;* thence down amain
By *Leo*, and the *Virgin*, and the *Scales*
As deep as *Capricorn*, to bring in change
Of seasons to each clime: else had the spring
Perpetual smil'd on earth with verdant flowers,
Equal in days and nights, except to those
Beyond the *polar* circles; to them day
Had unbenighted shone, while the low sun
To recompense his distance, in their sight
Had rounded still th' horizon.

PAR. LOST, Book X. l. 672.

James. In what manner is this prevented?

Tutor. By the axis of the earth N S (Plate VI. Fig. 7.) being inclined or bent about twenty-three degrees and a half out of the perpendicular as it is described by Milton:

> —— He bid his angles turn askance
> The poles of earth twice ten degrees and more
> From the sun's axis.

In this case you observe, that all the parallel circles, except the equator, are divided into two unequal parts, having a greater or less portion of their circumferences in the enlightened, than in the dark hemisphere, according to their situation with respect to N the north, or S the south pole.

Charles. At what season of the year is the earth represented in this figure?

Tutor. At our summer season: for you observe that the parallel circles in the northern hemisphere have their greater parts enlightened and their smaller parts in the dark. If D L represent that circle of latitude on the globe in which Great Britain is situated, it is evident that about two-thirds of it is in the light and only one-third in darkness.

You will remember that *parallels of latitude* are supposed circles on the surface of the earth, and are shown by real circles on its representa-

tive the terrestrial globe, drawn parallel to the equator.

James. Is that the reason why our days towards the middle of June are sixteen hours long, and the nights but eight hours?

Tutor. It is: and if you look to the parallel next beyond that marked D L, you will see a still greater disproportion between the day and night, and the parallel more north than this is entirely in the light.

Charles. Is it then all day there?

Tutor. To the whole space between that and the pole it is continual day for some time, the duration of which is in proportion to its vicinity to the pole; and at the pole there is a permanent day-light for six months together.

James. And during that time it must, I suppose, be night to the people who live at the south-pole?

Tutor. Yes, the figure shows that the south-pole is in darkness; and you may observe, that to the inhabitants living in equal parallels of latitude, the one north, and the other south, the length of the days to the one will be always equal to the length of the nights to the other.

Charles. What then shall we say of those who live at the equator, and consequently who have no latitude?

Tutor. To them the days and nights are *always* equal, and of course twelve hours each in

length, and this is also evident from the figure, for in every position of the globe one half of the equator is in the light and the other half in darkness.

James. If, then, the length of the days is the cause of the different seasons, there can be no variety in this respect, to those who live at the equator.

Tutor. You seem to forget that the change in the seasons depends upon the position of the earth with respect to the sun, that is, upon the *perpendicularity* with which the rays of light fall upon any particular part of the earth; as well as upon the length of days.

Charles. Does this make any material difference with regard to the heat of the sun?

Tutor. It does; let A B (Plate VI. Fig. 8.) represent a portion of the earth's surface, on which the sun's rays fall perpendicularly; let B C represent an equal portion on which they fall obliquely or aslant. It is manifest that B C, though it be equal to A B, receives but half the light and heat that A B does. Moreover, by the sun's rays coming more perpendicularly, they come with greater force, as well as in greater numbers, on the same place.

CONVERSATION XXXII.

Of the Seasons.

Tutor. Let us now take a view of the earth in its annual course round the sun, considering its axis as inclined 23½ degrees to a line perpendicular to its orbit, and keeping, through its whole journey, a direction parallel to itself; and you will find, that according as the earth is in different parts of its orbit, the rays of the sun are presented perpendicularly to the equator, and to every point of the globe, within 23½ degrees of it both north and south.

This figure (Plate VI. Fig. 9.) represents the earth in four different parts of its orbit, or as it is situated with respect to the sun in the months of March, June, September, and December.

Charles. The earth's orbit is not made circular in the figure.

Tutor. No: But the orbit itself is nearly circular, but we are, however, supposed to view it from the side B D, and therefore, though almost a circle, it appears to be a long ellipsis. All circles appear elliptical in an oblique view, as is evident, by looking obliquely at the rim of a basin, at some distance from you. For the true

figure of a circle can only be seen, when the eye is directly over its centre. You observe that the sun is not in the centre.

James. I do; and it appears nearer to the earth in the winter, than in the summer.

Tutor. We are indeed more than three millions of miles nearer to the sun in December than we are in June.

Charles. Is this possible? and yet our winter is so much colder than the summer.

Tutor. Notwithstanding this, it is a well-known fact. For it is ascertained, that our summer, that is, the time that passes between the vernal and autumnal equinoxes, is nearly eight days longer than our winter, or the time between the autumnal and vernal equinoxes. Consequently the motion of the earth is slower in the former case than in the latter, and therefore, as we shall see, it must be at a greater distance from the sun. Again, the sun's *apparent* diameter is greater in our winter than in summer, but the apparent diameter of any object increases in proportion as our distance from the object is diminished, and therefore we conclude, that we are nearer the sun in winter than in summer. The sun's apparent diameter in winter is 32′. .47″; in summer 31′. .40″.

James. But if the earth is farther from the sun in summer than in winter, why are our winters so much colder than our summers?

Tutor. Because first in the summer, the sun rises to a much greater height above our horizon, and therefore its rays coming more perpendicularly, more of them, as we showed you yesterday, must fall upon the surface of the earth, and come also with greater force, which is the principal cause of our great summer's heat. Secondly, in the summer, the days are very long, and the nights short; therefore the earth and air are heated by the sun in the day, more than they are cooled in the night.

James. Why have we not, then, the greatest heat at the time when the days are longest?

Tutor. The hottest season of the year is certainly a month or two after this, which may be thus accounted for. A body once heated does not grow cold again instantaneously, but gradually; now, as long as more heat comes from the sun in the day, than is lost in the night, the heat of the earth and air will be daily increasing, and this must evidently be the case for some weeks after the longest day, both on account of the number of rays which falls on a given space, and also from the perpendicular direction of those rays.

James. Will you now explain to us in what manner the seasons are produced?

Tutor. By referring to the figure (Plate VI. Fig. 9.) you will observe, that in the month of June, the north-pole of the earth inclines to-

wards the sun, and consequently brings all the northern parts of the globe more into light, than at any other time in the year.

Charles. Then to the people in those parts it is summer.

Tutor. It is: but in December, when the earth is in the opposite part of its orbit, the north-pole declines from the sun, which occasions the northern places to be more in the dark than in the light; and the reverse at the southern places.

James. Is it then summer to the inhabitants of the southern hemisphere?

Tutor. Yes, it is; and winter to us. In the months of March and September, the axis of the earth does not incline to, nor decline from, the sun, but is perpendicular to a line drawn from its centre. And then the poles are in the boundary of light and darkness, and the sun being directly vertical to, or over the equator, makes equal day and night at all places. Now trace the annual motion of the earth in its orbit for yourself, as it is represented in the figure.

Charles. I will, sir: about the 20th of March the earth is in Libra, and consequently to its inhabitants the sun will appear in Aries, and be vertical in the equator.

Tutor. And then the equator and all its parallels are equally divided between the light and dark.

Charles. Consequently the days and nights are

equal all over the world. As the earth pursues its journey from March to June, its northern hemisphere comes more into light, and on the 21st of that month, the sun is vertical to the tropic of Cancer.

Tutor. And you then observe that all the circles parallel to the equator are unequally divided; those in the northern half have their greater parts in the light, and those in the southern have their larger parts in darkness.

Charles. Yes; and of course it is summer to the inhabitants of the northern hemisphere, and winter to the southern.

I now trace it to September, where I find the sun vertical again to the equator, and of course, the days and nights are again equal. And following the earth in its journey to December, or when it has arrived at Cancer, the sun appears in Capricorn; and it is vertical to that part of the earth called the tropic of Capricorn, and now the southern pole is enlightened, and all the circles on that hemisphere have their larger parts in light, and, of course, it is summer to those parts, and winter to us in the northern hemisphere.

Tutor. Can you, James, now tell me why the days lengthen and shorten from the equator to the polar circles every year?

James. I will try to explain myself on the subject. Because the sun in March is vertical to the equator, and from that time to the 21st of

June it becomes vertical successively to all other parts of the earth between the equator and the tropic of Cancer, and in proportion as it becomes vertical to the more northern parts of the earth, it declines from the southern, and, consequently, to the former the days lengthen, and to the latter they shorten. From June to September the sun is again vertical successively to all the same parts of the earth, but in a reverse order.

Charles. Since it is summer to all those parts of the earth, where the sun is vertical, and we find that the sun is vertical twice in the year to the equator, and every part of the globe between the equator and tropics, there must be also two summers in a year to all those places.

Tutor. There are; and in those parts near the equator, they have two harvests every year.—But let your brother finish his description.

James. From September to December, it is successively vertical to all the parts of the earth situated between the equator and the tropic of Capricorn, which is also the cause of the lengthening of the days in the southern hemisphere, and of their becoming shorter in the northern.

Tutor. Can you, Charles, tell me why there is sometimes no day or night for some little time together within the polar circles?

Charles. The sun always shines upon the earth 90 degrees every way, and when he is vertical to the tropic of Cancer, which is 23½ degrees north

of the equator, he must shine the same number of degrees beyond the pole, or to the polar circle, and while he thus shines, there can be no night to the people within that polar circle; and, of course, to the inhabitants at the southern polar circle, there can be no day at the same time, for as the sun's rays reach but 90 degrees every way, they cannot shine far enough to reach them.

Tutor. Tell me, now, why there is but one day and night in the whole year at the poles?

Charles. For the reason which I have just given, the sun must shine beyond the north-pole all the time he is vertical to those parts of the earth, situated between the equator and the tropic of Cancer, that is, from March the 21st, to September the 20th, during which time there can be no night at the north-pole, nor any day at the south-pole. The reverse of this may be applied to the southern pole.

James. I understand now, that the lengthening and shortening of the days, and different seasons, are produced by the annual motion of the earth round the sun; the axis of the earth, in all parts of its orbit, being kept parallel to itself. But if thus parallel to itself, how can it in all positions point to the pole-star in the heavens?

Tutor. Because the diameter of the earth's orbit A C is nothing in comparison of the distance of the earth from the fixed stars. Suppose you draw two parallel lines at the distance of three or four yards from one another, will they

not both point to the moon when she is in the horizon?

James. Three or four yards cannot be accounted as any thing, in comparison of 240 thousand miles, the distance of the moon from us.

Tutor. Perhaps three yards bear a much greater proportion to 240 thousand miles, than 190 millions of miles bear to our distance from the polar star.

CONVERSATION XXXIII.

Of the Equation of Time.

Tutor. You are now, I presume, acquainted with the motions peculiar to this globe on which we live?

Charles. Yes: it has a rotation on its axis from west to east every 24 hours, by which day and night are produced, and also the apparent diurnal motion of the heavens from east to west.

James. The other is its annual revolution in an orbit round the sun, likewise from west to east, at the distance of about 95 millions of miles from the sun.

Tutor. You understand also, in what manner this annual motion of the earth, combined with the inclination of its axis, is the cause of the variety of seasons.

We will therefore proceed to investigate another curious subject, viz. the equation of time, and to explain to you the difference between *equal* and *apparent* time.

Charles. Will you tell us what you mean by the words *equal* and *apparent*, as applied to time?

Tutor. *Equal* time is measured by a clock, that is supposed to go without any variations, and to measure exactly 24 hours from noon to noon. And *apparent* time is measured by the *apparent* motion of the sun in the heavens, or by a good sun-dial.

Charles. And what do you mean, sir, by the *equation of time?*

Tutor. It is the adjustment of the difference of time, as shown by a well-regulated clock and a true sun-dial.

James. Upon what does this difference depend?

Tutor. It depends *first*, upon the inclination of the earth's axis. And *secondly* upon the elliptic form of the earth's orbit; for, as we have already seen, the earth's orbit being an ellipse, its motion is quicker when it is in *perihelion*, or nearest to the sun; and slower when it is in *aphelion*, or farthest from the sun.

Charles. But I do not yet comprehend what

the rotation of the earth has to do with the going of a clock or watch.

Tutor. The rotation of the earth is the most equable and uniform motion in nature, and is completed in 23 hours, 56 minutes, and 4 seconds; this space of time is called a *sidereal* day, because any meridian on the earth will revolve from a fixed star to that star again, in this time. But a *solar* or natural day, which our clocks are intended to measure, is the time which any meridian on the earth will take in revolving from the sun to the sun again, which is about 24 hours, sometimes a little more, but generally less.

James. What occasions this difference between the solar and sidereal day?

Tutor. The distance of the fixed stars is so great, that the diameter of the earth's orbit, though 190 millions of miles, when compared with it, is but a point, and therefore any meridian on the earth will revolve from a fixed star to that star again in exactly the same time, as if the earth had only a diurnal motion, and remained always in the same part of its orbit. But with respect to the sun, as the earth advances almost a degree eastward in its orbit, in the same time that it turns eastward round its axis, it must make more than a complete rotation before it can come into the same position with the sun that it had the day before. In the same way, as when both the hands of a watch or clock set off together, at twelve o'clock, the minute-hand must

travel more than a whole circle before it will overtake the hour-hand, that is, before they will be in the same relative position again. Thus the sidereal days are shorter than the solar ones by about four minutes, as is evident from observation:

> Watch with nice eye the earth's diurnal way,
> Marking her *solar* and *sidereal* day;
> Her slow nutation, and her varying clime,
> And trace with mimic art the march of time.
>
> BOTANIC GARDEN.

Charles. Still I do not understand the reason why the clocks and dials do not agree.

Tutor. A good clock is intended to measure that equable and uniform time which the rotation of the earth on its axis exhibits. Whereas the dial measures time by the *apparent* motion of the sun, which, as we have explained, is subject to variation.. Or thus: though the earth's motion on its axis be perfectly uniform, and consequently the rotation of the *equator*, the plane of which is perpendicular to the axis, or of any other circle parallel to it, be likewise equable, yet we measure the length of the natural day by means of the sun, whose *apparent* annual motion is not in the equator, or any of its parallels, but in the ecliptic, which is oblique to it.

James. Do you mean by this that the equator of the earth, in its annual journey, is not always directed towards the centre of the sun?

Tutor. I do: twice only in the year, a line

drawn from the centre of the sun to that of the earth passes through those points where the equator and ecliptic cross one another; at all other times, it passes through some other part of that oblique circle, which is represented on the globe by the ecliptic line. Now when it passes through the equator or the tropics, which are circles parallel to the equator, the sun and the clocks go together as far as regards this cause, but at other times they differ, because *equal* portions of the ecliptic pass over the meridian in *unequal* parts of time on account of its obliquity.

Charles. Can you explain this by a figure?

Tutor. It is easily shown by the globe which this figure ♈ N ♎ S (Plate VI. Fig. 10.) may represent; ♈ ♎ will be the equator, ♈ ♋ ♎ the northern half the ecliptic, and ♈ ♑ ♎ the southern half. Make chalk or pencil marks *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, all round the *equator* and *ecliptic*, at equal distances (suppose 30 degrees) from each other, beginning at Aries. Now by turning the globe on its axis, you will perceive that all the marks in the first quadrant of the *ecliptic*, that is, from Aries to Cancer, come sooner to the brazen meridian than their corresponding marks on the *equator:* —those from the beginning of Cancer to Libra come *later*:—those from Capricorn sooner:—and those from Capricorn to Aries later.

Now time as measured by the sun-dial is represented by the marks on the *ecliptic*; that

measured by a good clock, by those on the *equator.*

Charles. Then while the sun is in the first and third quarters, or what is the same thing, while the earth is travelling through the second and fourth quarters, that is, from Cancer to Libra, and from Capricorn to Aries, the sun is faster than the clocks, and while it is travelling the other two quarters it is slower.

Tutor. Just so: because while the earth is travelling through the second and fourth quadrants, equal portions of the ecliptic come *sooner* to the meridian than their corresponding parts of the equator: and during its journey through the first and third quadrants, the equal parts of the ecliptic arrive *later* at the meridian than their corresponding parts of the equator.

James. If I understand what you have been saying, the dial and clocks ought to agree at the equinoxes, that is, on the 20th of March, and the 23d of September, but if I refer to the Ephemeris, I find that on the former day (1809) the clock is 8 minutes before the sun: and on the latter day the clock is almost 8 minutes behind the sun.

Tutor. If this difference between time measured by the dial and clock depended only on the inclination of the earth's axis to the plane of its orbit, the clocks and dials ought to be together at the equinoxes, and also on the 21st of June and the 21st of December, that is, at the sum-

mer and winter solstices; because, on those days, the *apparent* revolution of the sun is parallel to the equator. But I told you there was another cause why this difference subsisted.

Charles. You did: and that was the elliptic form of the earth's orbit.

Tutor. If the earth's motion in its orbit were uniform, which it would be if the orbit were circular, then the whole difference between *equal* time as shown by the clock, and *apparent* time as shown by the sun, would arise from the inclination of the earth's axis. But this is not the case; for the earth travels, when it is nearest the sun, that is, in the winter, more than a degree in 24 hours, and when it is farthest from the sun, that is, in summer, less than a degree in the same time: consequently from this cause the natural day would be of the greatest length when the earth was nearest the sun, for it must continue turning the longest time after an entire rotation, in order to bring the meridian of any place to the sun again: and the shortest day would be when the earth moves the slowest in her orbit. Now these inequalities, combined with those arising from the inclination of the earth's axis, make up that difference which is shown by the equation table, found in the Ephemeris, between good clocks and true sun-dials.

CONVERSATION XXXIV.

Of Leap Year.

James. Before we quit the subject of time, will you give us some account of what is called in our almanacs Leap-Year?

Tutor. I will. The length of our year is, as you know, measured by the time which the earth takes in performing her journey round the sun, in the same manner as the length of the day is measured by its rotation on its axis. Now, to compute the exact time taken by the earth in its annual journey, was a work of considerable difficulty. Julius Cæsar was the first person who seems to have attained to any accuracy on this subject.

Charles. Do you mean the first Roman emperor, who landed also in Great-Britain?

Tutor. I do. He was not less celebrated as a man of science, than he was renowned as a general: of him it was said,

> Amidst the hurry of tumultuous war,
> The stars, the gods, the heavens were still his care;
> Nor did his skill to fix the rolling year,
> Inferior to Eudoxus's art appear.

Julius Cæsar, who was well acquainted with the learning of the Egyptians, fixed the length of the year to be 365 days and six hours, which made it six hours longer than the Egyptian year. Now, in order to allow for the odd six hours in each year, he introduced an additional day every fourth year, which accordingly consists of 366 days, and is called *Leap*-Year, while the other three have only 365 days each. From him it was denominated the *Julian* year.

James. It is also called *Bissextile* in the Almanacs: what does that mean?

Tutor. The Romans inserted the intercalary day between the 23d and 24th of February: and because the 23d of February, in their calendar, was called *sexto calendas Martii*, the sixth of the calends of March; the intercalated day was called *bis sexto calendas Martii*, the second sixth of the calends of March, and hence the year of intercalation had the appellation of *Bissextile.* This day was chosen at Rome, on account of the expulsion of Tarquin from the throne, which happened on the 23d of February. We introduce, in Leap-Year, a new day in the same month, namely, the 29th.

Charles. Is there any rule for knowing what year is Leap-Year?

Tutor. It is known by dividing the date of the year by 4, if there be no remainder, it is Leap-Year; thus 1799 divided by 4, leaves a remain-

der of 3, showing that it is the 3d year after Leap-Year. These two lines contain the rule:

> Divide by 4; what's left shall be
> For Leap-Year 0; for past 1, 2, 3.

James. The year, however, does not consist of 365 days and 6 hours, but of 365 days, 5 hours, 48 minutes, and 49 seconds.* Will not this occasion some error?

Tutor. It will; and by subtracting the latter number from the former, you will find that the error amounts to 11 minutes and 11 seconds every year, or to a whole day in about 130 years: notwithstanding this, the Julian year continued to be in general use till the year 1582, when Pope Gregory XIII. undertook to rectify the error, which, at that time, amounted to ten days. He accordingly commanded the ten days between the 4th and 15th of October in that year to be suppressed, so that the 5th day of that month was called the 15th. This alteration took place through the greater part of Europe, and the year was afterwards called the Gregorian year, or *New Style*. In this country, the method of reckoning, according to the New Style, was not admitted into our calendars until the year 1752, when the error amounted to nearly 11 days, which were taken from the month of September, by calling the 3d of that month the 14th.

* See Conversation XXX.

Charles. By what means will this accuracy be maintained?

Tutor. The error amounting to one whole day in about 130 years, it is settled by an act of parliament, that the year 1800 and the year 1900, which are, according to the rule just given, Leap-Years, shall be computed as common years, having only 365 days in each: and that every *four* hundredth year afterwards should be common years also. If this method be adhered to, the present mode of reckoning will not vary a single day from true time, in less than 5000 years.

By the same act of parliament, the legal beginning of the year was changed from the 25th of March to the 1st of January. So that the succeeding months of January, February, and March, up to the 24th day, which would, by the Old Style, have been reckoned part of the year 1752, were accounted as the first three months of the year 1753. Hence we sometimes see such a date as this, Feb. 10, 1774–5, that is, according to the Old Style it was 1774, but according to the New it is 1775, because now the year begins in January instead of March.

CONVERSATION XXXV.

Of the Moon.

Tutor. You are now, gentlemen, acquainted with the reasons for the division of time into days and years.

Charles. These divisions have their foundation in nature, the *former* depending upon the rotation of the earth on its axis; the *latter* upon its revolution in an elliptic orbit about the sun as a centre of motion.

James. Is there any natural reason for the division of years into weeks, or of days into hours, minutes, and seconds?

Tutor. These divisions were invented entirely for the convenienee of mankind, and are accordingly different in different countries. There is, however, another division of time marked out by nature.

Charles. What is that, sir?

Tutor. The length of the *month:* not indeed that month which consists of four weeks, nor that by which the year is divided into twelve parts. These are both arbitrary. But by a month is meant the time which the moon takes in performing her journey round the earth:

> Then mark'd astronomers with keener eyes
> The moon's refulgent journey through the skies.
>
> DARWIN.

James. How many days does the moon take for this purpose?

Tutor. If you refer to the time in which the moon revolves from one point of the heavens to the same point again, it consists of 27 days, 7 hours, and 48 minutes, this is called the *periodical* month: but if you refer to the time passed from new moon to new moon again, the month consists of 29 days, 12 hours, and 44 minutes, this is called the *synodical* month.

Charles. Pray explain the reason of this difference.

Tutor. It is occasioned by the earth's annual motion in its orbit. Let us refer to our watch as an example. The two hands are together at 12 o'clock; now when the minute-hand has made a complete revolution, are they together again?

James. No; for the hour-hand is advanced the twelfth part of its revolution, which in order that the other may overtake, it must travel five minutes more than the hour.

Tutor. And something more, for the hour-hand does not wait at the figure I, till the other comes up: and therefore they will not be together till between 5 and 6 minutes after one.

Now apply this to the earth and moon, suppose (Plate VII. Fig. 11.) S to be the sun; T the earth in a part of its orbit Q L; and E to be the position of the moon; if the earth had no mo-

tion, the moon would move round its orbit E H C into the position E again, in 27 days, 7 hours, 43 minutes; but while the moon is describing her journey, the earth has passed through nearly a twelfth part of her orbit, which the moon must also describe before the two bodies come again into the same position that they before held with respect to the sun: this takes up so much more time as to make her synodical month equal to 29 days, 12 hours, and 44 minutes; hence the foundation of the division of time into months.

We will now proceed to describe some other particulars relating to the moon, as a body depending, like the earth, on the sun for her light and heat.

Charles. Does the moon shine with a borrowed light only?

Tutor. This is certain; for otherwise, if like the sun, she were a luminous body, she would always shine with a full orb as the sun does:

> ——————Less bright the moon,
> But opposite in level'd west was set,
> His mirror, with full face *borrowing* her light
> From him, for other lights she needed none.

Her diameter is nearly 2200 miles in length.

James. And I remember she is at the distance of 240,000 miles from the earth.

Tutor. The sun S (Plate VII. Fig. 11.) always enlightens one half of the moon E, and its whole

enlightened hemisphere, or a part of it, or none at all, is seen by us, according to her different positions in the orbit with respect to the earth, for only those parts of the enlightened half of the moon are visible at T, which are cut off by, and are *within* the orbit.

James. Then when the moon is at E, no part of its enlightened side is visible to the earth.

Tutor. You are right: it is then *new* moon, or *change*, for it is usual to call it new moon the first day it is visible to the earth, which is not till the second day after the change. And the moon being in a line between the sun and earth, they are said to be in *conjunction*.

Charles. And at A all the illuminated hemisphere is turned to the earth.

Tutor. This is called *full* moon; and the earth being between the sun and moon, they are said to be in *opposition*. The enlightened parts of the little figures on the outside of the orbit, represent the appearance of the moon as seen by a spectator on the earth.

James. Is the little figure then opposite E wholly dark to show that the moon is invisible at *change?*

Tutor. It is; and when it is at F a smaller part of the illuminated hemisphere is *within* the moon's orbit, and therefore to a spectator on the earth it appears *horned*: at G one half of the enlightened hemisphere is visible, and it is said to be in *quadrature;* at H three-fourths of the en-

lightened part is visible to the earth, and it is then said to be *gibbous:* and at A the enlightened face of the moon is turned to the earth, and it is said to be *full.* The same may be said of the rest.

The horns of the moon before conjunction or new moon, are turned to the *east:* after conjunction they are turned to the *west.* How beautifully is the moon described by Milton:

————till the moon,
Rising in clouded majesty, at length,
Apparent Queen unveil'd her peerless light,
And o'er the night her silver mantle threw.
Book iv. line 606.

Charles. I see the figure is intended to show that the moon's orbit is elliptical; does she also turn upon her axis?

Tutor. She does; and she requires the same time for her diurnal rotation, as she takes in completing her revolution about the earth; and consequently though every part of the moon is successively presented to the sun, yet the same hemisphere is always turned to the earth. This is known by observation with good telescopes.

James. Then the length of a day and night in the moon is equal to more than twenty-nine days and a half of ours.

Tutor. It is so: and therefore as the length of her year, which is measured by her journey round the sun, is equal to that of ours, she can

have but about twelve days and one-third in a year. Another remarkable circumstance relating to the moon, is that the hemisphere next the earth is never in darkness, for in the position E when it is turned from the sun, it is illuminated by light reflected from the earth, in the same manner as we are enlightened by a full moon. But the other hemisphere of the moon has a fortnight's light and darkness by turns.

Charles. Can the earth, then, be considered as a satellite to the moon?

Tutor. It would, perhaps, be inaccurate to denominate the larger body a satellite to the smaller, but with regard to affording reflected light, the earth is to the moon, what the moon is to the earth, and subject to the same changes of horned, gibbous, full, &c.

Charles. But it must appear much larger than the moon.

Tutor. The earth will appear to the inhabitants of the moon, about 13 times as large as the moon appears to us. When it is *new moon* to us, it is *full earth* to them, and the reverse.

James. Is the moon then inhabited as well as the earth?

Tutor. Though we cannot demonstrate this fact, yet there are many reasons to induce us to believe it; for the moon is a secondary planet of considerable size;—its surface is diversified like that of the earth, with mountains and valleys;—the former have been measured by Dr.

Herschel, and some of them found to be about a mile in height. The situation of the moon, with respect to the sun, is much like that of the earth, and by a rotation on her axis, and a small inclination of that axis to the plane of her orbit, she enjoys, though not a considerable, yet an agreeable variety of day and night and of seasons. To the moon, our globe appears a capital satellite, undergoing the same changes of illumination as the moon does to the earth. The sun and stars rise and set there as they do here, and heavy bodies will fall on the moon as they do on the earth. Hence we are led to conclude that, like the earth, the moon also is inhabited. Dr. Herschel discovered some years ago three volcanoes all burning in the moon; but no large seas or tracts of water have been observed there, nor is the existence of a lunar atmosphere certain. Therefore her inhabitants must materially differ from those who live upon the earth.

CONVERSATION XXXVI.

Of Eclipses.

Charles. Will you, sir, explain to us the nature and causes of eclipses?

Tutor. I will, with great pleasure. You must observe, then, that eclipses depend upon this simple principle, that all opaque or dark bodies when exposed to any light, and therefore to the light of the sun, cast a shadow behind them in an opposite direction.

James. The earth being a body of this kind must cast a very large shadow on its side which is opposite to the sun.

Tutor. It does: and an eclipse of the moon happens when the earth T (Plate VII. Fig. 12.) passes between the sun S and the moon M, and it is occasioned by the earth's shadow being cast on the moon.

Charles. When does this happen?

Tutor. It is only when the moon is full or in *opposition*, that it comes within the shadow of the earth.

James. Eclipses of the moon, however, do not happen every time it is full: what is the reason of this?

Tutor. Because the orbit of the moon does not coincide with the plane of the earth's orbit, but one half of it is elevated about five degrees and a third above it, and the other half is as much below it: and therefore, unless the full moon happen in or near one of the nodes, that is, in or near the points in which the two orbits intersect each other, she will pass above or below the shadow of the earth, in which case there can be no eclipse.

Charles. What is the greatest distance from the node, at which an eclipse of the moon can happen?

Tutor. There can be no eclipse, if the moon, at the time when she is full, be more than 12 degrees from the node; when she is within that distance, there will be a *partial* or *total* eclipse, according as a part, or the whole disk or face of the moon falls within the earth's shadow. If the eclipse happen exactly when the moon is full in the node, it is called a central eclipse.

James. I suppose the duration of the eclipse lasts all the time that the moon is passing through the shadow.

Tutor. It does: and you observe that the shadow is considerably wider than the moon's diameter, and therefore an eclipse of the moon lasts sometimes three or four hours. The shadow also you perceive is of a conical shape, and consequently, as the moon's orbit is an ellipse and not a circle, the moon will, at different times, be

eclipsed when she is at different distances from the earth.

Charles. And according as the moon is nearer to, or farther from the earth, the eclipse will be of a greater or less duration, for the shadow being conical, becomes less and less, as the distance from the body by which it is cast is greater.

Tutor. It is by knowing exactly at what distance the moon is from the earth, and of course the width of the earth's shadow at that distance, that all eclipses are calculated with the greatest accuracy, for many years before they happen. Now, it is found that in all eclipses, the shadow of the earth is conical, which is a demonstration, that the body by which it is projected is of a spherical form, for no other sort of figure would, in *all positions*, cast a conical shadow. This is mentioned as another proof, that the earth is a spherical body.

James. It seems to me to prove another thing, viz. that the sun must be a larger body than the earth.

Tutor. Your conclusion is just, for if the two bodies were equal to one another (Plate VII. Fig. 13.) the shadow would be cylindrical: and if the earth were the larger body, (Plate VII. Fig. 14.) its shadow would be of the figure of a cone, which had lost its vertex, and the farther it were extended the larger would it become. In either case the shadow would run out to an infi-

nite space, and accordingly must sometimes involve in it the other planets, and eclipse them, which is contrary to fact. Therefore, since the earth is neither larger than, nor equal to the sun, it must be the lesser body. We will now proceed to the eclipses of the sun.

Charles. How are these occasioned?

Tutor. An eclipse of the sun happens when the moon M, passing between the sun S and the earth T (Plate VII. Fig. 15.) intercepts the sun's light.

James. The sun then can be eclipsed only at the new moon.

Tutor. Certainly; for it is only when the moon is in *conjunction* that it can pass directly between the sun and earth.

Charles. It is only when the moon at her conjunction, is near one of its nodes, that there can be an eclipse of the sun?

Tutor. An eclipse of the sun depends upon this circumstance: for unless the moon is in, or near one of its nodes, she cannot appear in the same plane with the sun, or seem to pass over his disk. In every other part of the orbit she will appear above or below the sun. If the moon be *in* one of the nodes, she will, in most cases, cover the whole disk of the sun, and produce a *total* eclipse; if she be any where within about 16 degrees of a node, a *partial* eclipse will be produced.

The sun's diameter is supposed to be divided into 12 equal parts, called *digits*, and in every

partial eclipse, as many of these parts of the sun's diameter as the moon covers, so many digits are said to be eclipsed.

James. I have heard of *annular* eclipses, what are they, sir?

Tutor. When a ring of light appears round the edge of the moon during an eclipse of the sun, it is said to be annular, from the Latin word *annulus*, a *ring:* these kind of eclipses are occasioned by the moon being at her greatest distance from the earth at the time of an eclipse, because in that situation the vertex or tip of the cone of the moon's shadow does not reach the surface of the earth.

Charles. How long can an eclipse of the sun last?

Tutor. A total eclipse of the sun is a very curious and uncommon spectacle: and total darkness cannot last more than three or four minutes. Of one that was observed in Portugal, 150 years ago, it is said that the darkness was greater than that of the night:—that stars of the first magnitude made their appearance;—and that the birds were so terrified that they fell to the ground.

James. Was this visible only at Portugal?

Tutor. It must have been seen at other places, though we have no account of it. The moon, however, being a body much smaller than the earth, and having also a conical shadow, can with that shadow only cover a small part of the

earth; whereas an eclipse of the moon may be seen by all those that are on the hemisphere which is turned towards it. (See Plate VII. Fig. 15 and 12.)

You will also observe, that an eclipse of the sun may be *total* to the inhabitants near the middle of the earth's disk, and *annular* to those in places near the edges of the disk, for in the former case the moon's shadow will reach the earth, and in the latter, on account of the earth's sphericity, it will not.

Charles. Have not eclipses been esteemed as omens presaging some direful calamity?

Tutor. Till the causes of these appearances were discovered, they were generally beheld with terror by the inhabitants of the world, which is beautifully alluded to by Milton, in the first book of Paradise Lost, line 594:

> ——————As when the sun, new risen,
> Looks through the horizontal misty air
> Shorn of his beams, or from behind the moon,
> In dim eclipse, disastrous twilight sheds
> On half the nations, and with fear of change
> Perplexes monarchs.

CONVERSATION XXXVII.

Of the Tides.

Tutor. We will proceed to the consideration of the *tides*, or the flowing and ebbing of the ocean.

James. Is this subject connected with astronomy?

Tutor. It is, inasmuch as the tides are occasioned by the attraction of the sun and moon upon the waters, but more particularly by that of the latter. You will readily perceive that the tides are dependent upon some known and determinate laws, because, if you turn to the Ephemeris, or indeed to almost any almanac, you will see that the exact time of high water at London-bridge for every day in the year is set down.

Charles. I have frequently wondered how this could be known with such a degree of accuracy: indeed there is not a waterman that plies at the stairs, but can readily tell when it will be high water.

Tutor. The generality of the watermen are probably as ignorant as yourself of the cause by which the waters flow and ebb, but by experience they know that the time of high water differs on each day about three quarters of an hour, or a little more or less, and therefore if it

be high water to-day at six o'clock, they will, at a guess, tell you, that to-morrow the tide will not be up till a quarter before seven.

James. Will you explain the causes?

Tutor. I will endeavour to do this in an easy and concise manner, without fatiguing your memory with a great variety of particulars:

> The ebbs of tides, and their mysterious flow,
> We, as art's elements, shall understand.
>
> DRYDEN.

You must bear in your mind then, that the tides are occasioned by the attraction of the sun and moon upon the waters of the earth: perhaps a figure may be of some assistance to you. Let A *p* L *n* (Plate VII. Fig. 16.) be supposed the earth, C its centre; let the dotted circle represent a mass of water covering the earth: let M be the moon in its orbit, and S the sun.

Since the force of gravity or attraction diminishes as the squares of the distances increase,* the waters on the side A are more attracted by the moon M, than the central parts at C; and the central parts are more attracted than the waters at L; consequently the waters at L will recede from the centre; therefore while the moon is in the situation M, the waters will rise towards *a* and *b* on the opposite sides of the earth.

Charles. You mean that the waters will rise

*See p. 37.

at *a* by the immediate attraction of the moon M, and will rise at *b*, by the centre C receding, and leaving them more elevated there.

Tutor. That is the explanation. It is evident that the quantity of water being the same, a rise cannot take place at *a* and *b*, without the parts at P and N being at the same time depressed.

James. In this situation the water may be considered as partaking of an oval form.

Tutor. If the earth and moon were without motion, and the earth covered all over with water, the attraction of the moon would raise it up in a heap in that part of the ocean to which the moon is vertical, and there it would always continue; but by the rotation of the earth on its axis, each part of its surface to which the moon is vertical is presented twice a day to the action of the moon, and thus are produced two floods and two ebbs;

> Alternate tides in sacred order run.
>
> BLACKMORE.

Charles. How twice a day?

Tutor. In the position of the earth and moon as it is in our figure, the waters are raised at A by the direct attraction of the moon, and a tide is accordingly produced: but when, by the earth's rotation, A comes, 12 hours afterwards, into the position L, another tide is occasioned

by the receding of the waters there from the centre.

James. You have told us that the tides are produced in those parts of the earth to which the moon is vertical, but this effect is not confined to those parts.

Tutor. It is not, but there the attraction of the moon has the greatest effect; in all other parts her force is weaker, because it acts in a more oblique direction.

Charles. Are there two tides in every 24 hours?

Tutor. If the moon were stationary this would be the case; but because that body is also proceeding every day about 13 degrees from west to east in her orbit, the earth must make more than one revolution on its axis before the same meridian is in conjunction with the moon, and hence two tides take place in about 24 hours and 50 minutes.

James. But I remember when we were at the sea, that the tides rose higher at some seasons than at others; how do you account for this?

Tutor. The moon goes round the earth in an elliptic orbit, and therefore she approaches nearer to the earth in some parts of her orbit, than in others. When she is nearest, the attraction is the strongest, and consequently it raises the tides most: and when she is farthest from the earth, her attraction is the least, and the tides the lowest.

James. Do they rise to different heights in different places?

Tutor. They do: in the Black-Sea and the Mediterranean the tides are scarcely perceptible. At the mouth of the Indus the water rises and falls full 30 feet. The tides are remarkably high on the coast of Malay, in the Straits of Sunda, in the Red-Sea, along the coast of China, Japan, &c. In general the tides rise highest and strongest in those places that are narrowest.

Charles. You said the sun's attraction occasioned tides as well as that of the moon.

Tutor. It does: but owing to the immense distance of the sun from the earth, it produces but a small effect in comparison of the moon's attraction. Sir Isaac Newton computed, that the force of the moon raised the waters in the great ocean 10 feet; whereas that of the sun raised it only two feet. When both the attraction of the sun and moon act in the same direction, that is, at new and full moon, the combined forces of both raise the tide 12 feet. But when the moon is in her quarters, the attraction of one of these bodies raises the water, while that of the other depresses it; and therefore the smaller force of the sun must be subtracted from that of the moon, consequently the tides will be no more than 8 feet. The highest tides are called spring-tides, and the lowest are denominated neap-tides.

James. I understand that in the former case,

the height to which the tides are raised must be calculated by *adding* together the attractions of the sun and moon; and in the latter, it must be estimated by the *difference* of these attractions.

Tutor. You are right. When the sun and moon are both vertical to the equator of the earth, and the moon at her least distance from the earth, then the tides are highest.

Charles. Do the highest tides happen at the Equinoxes?

Tutor. Strictly speaking, these tides do not happen till some little time after, because in this, as in other cases, the actions do not produce the greatest effect when they are at the strongest, but some time afterwards: thus the hottest part of the day is not when the sun is on the meridian, but between two and four o'clock in the afternoon.—Another circumstance must be taken into consideration: the sun being nearer to the earth in winter than in summer, it is of course nearer to it in February and October, than in March and September; and therefore all these things being put together, it will be found that the greatest tides happen a little before the vernal, and some time after the autumnal Equinoxes.

CONVERSATION XXXVIII.

Of the Harvest Moon.

Tutor. From what we said yesterday, you will easily understand the reason why the moon rises about three quarters of an hour later every day than on the one preceding.

Charles. It is owing to the daily progress which the moon is making in her orbit, on which account any meridian on the earth must make more than one complete rotation on its axis, before it comes again into the same situation with respect to the moon that it had before. And you told us that this occasioned a difference of about 50 minutes.

Tutor. At the equator this is generally the difference of time between the rising of the moon on one day and the preceding. But in places of considerable latitude, as that in which we live, there is a remarkable difference about the time of harvest, when at the season of full moon she rises for several nights together only about 20 minutes later on the one day than on that immediately preceding. By thus succeeding the sun before the twilight is ended, the moon prolongs the light, to the great benefit of those who are engaged in gathering in the fruits of the earth:

and hence the full moon at this season is called the harvest moon. It is believed that this was observed by persons engaged in agriculture, at a much earlier period than it was noticed by astronomers; the former ascribed it to the goodness of the Deity, not doubting but that he had so ordered it on purpose for their advantage.

James. But the people at the equator do not enjoy this benefit.

Tutor. Nor is it necessary that they should, for in those parts of the earth, the seasons vary but little, and the weather changes but seldom, and at stated times; to them, then, moon-light is not wanting for gathering the fruits of the earth.

Charles. Can you explain how it happens, that the moon at this season of the year rises one day after another with so small a difference of time?

Tutor. With the assistance of a globe I could at once clear the matter up. But I will endeavour to give you a general idea of the subject without that instrument. That the moon loses more time in her risings when she is in one part of her orbit, and less in another, is occasioned by the moon's orbit lying sometimes more oblique to the horizon than at others.

James. But the moon's path is not marked on the globe.

Tutor. It is not; you may, however, consi-

der it, without much error, as coinciding with the ecliptic. And in the latitute of London, as much of the ecliptic rises about *Pisces* and *Aries* in two hours, as the moon goes through in six days; therefore while the moon is in these signs she differs but two hours in rising for six days together; that is, one day with another, about 20 minutes later every day than on the preceding:

> There is a time well known to husbandmen,
> In which the moon for many nights, in aid
> Of their autumnal labours, cheers the dusk
> With her full lustre, soon as Phœbus hides
> Beneath the horizon his propitious ray:
> For as the angle of the line which bounds
> The moon's career from the Equator, flows
> Greater or less, the orb of Cynthia shines.
> With less or more of difference in rise;
> In *Aries* least this angle: thence the moon
> Rises with smallest variance of times,
> When in this sign she dwells; and most protracts
> Her sojourning in our enlighten'd skies.
>
> LOFFT.

Charles. Is the moon in those signs at the time of harvest?

Tutor. In August and September you know that the sun appears in Virgo and Libra, and of course when the moon is *full*, she must be in the opposite signs, viz. *Pisces* and *Aries*.

James. Are there then two full moons that afford us this advantage?

Tutor. There are, the one when the sun is in

Virgo, which is called the *harvest* moon; the other when the sun is in Libra, and which, being less advantageous, is called the *hunter's* moon. You ought to be told that when the moon is in Virgo and Libra, then she rises with the greatest difference of time, viz. an hour and a quarter later every day than the former.

Charles. Will you explain, sir, how it is that the people at the equator have no harvest moon?

Tutor. At the equator, the north and south poles lie in the horizon, and therefore the ecliptic makes the same angle southward with the horizon when Aries rises, as it does northward when Libra rises: but as the harvest moon depends upon the different angles, at which different parts of the ecliptic rise, it is evident there can be no harvest moon at the equator.

The farther any place is from the equator, if it be not beyond the polar circles, the angle which the ecliptic makes with the horizon, when Pisces and Aries rise, gradually diminishes, and therefore when the moon is in these signs she rises with a nearly proportionable difference later every day than on the former, and this is more remarkable about the time of full moon.

James. Why have you excepted the space on the globe beyond the polar circles?

Tutor. At the polar circles, when the sun touches the summer tropic, he continues 24 hours above the horizon; and 24 hours below it when he touches the winter tropic. For the same

reason the full moon neither rises in the summer, when she is not wanted; nor sets in the winter, when her presence is so necessary. These are the only two full moons which happen about the tropics; for all the others rise and set. In summer the full moons are low, and their stay above the horizon short: in winter they are high, and stay long above the horizon. A wonderful display this of the divine wisdom and goodness, in apportioning the quantity of light suitable to the various necessities of the inhabitants of the earth, according to their different situations.

Charles. At the poles, the matter is, I suppose, still different.

Tutor. There one half of the ecliptic never sets, and the other half never rises; consequently the sun continues one half year above the horizon, and the other half below it. The full moon being always opposite to the sun, can never be seen by the inhabitants of the poles, while the sun is above the horizon. But all the time that the sun is below the horizon, the full moons never set. Consequently to them the full moon is never visible in the summer; and in their winter they have her always before and after the full, shining for fourteen of our days and nights without intermission. And when the sun is depressed the lowest under the horizon, then the moon ascends with her highest altitude.

James. This indeed exhibits in a high degree

the attention of Providence to all his creatures. But if I understand you, the inhabitants of the poles have in their winter a fortnight's light and darkness by turns.

Tutor. This would be the case for the whole six months that the sun is below the horizon, if there were no refraction;* and no substitute for the light of the moon. But by the atmosphere's refracting the sun's rays, he becomes visible a fortnight sooner, and continues a fortnight longer in sight than he would otherwise do, were there no such property belonging to the atmosphere. And in those parts of the winter, when it would be absolutely dark in the absence of the moon, the brilliancy of the *Aurora Borealis* is probably so great, as to afford a very comfortable degree of light. Mr. Hearne, in his travels near the polar circle, has this remark in his journal: "December 24. The days were so short, that the sun only took a circuit of a few points of the compass above the horizon, and did not at its greatest altitude rise half way up the trees. The brilliancy of the Aurora Borealis, however, and of the stars, even without the assistance of the moon, made amends for this deficiency, for it was frequently so light all night, that I could see to read a small print."

* The subject of refraction will be very particularly explained when we come to Optics.

These advantages are poetically described by our Thomson:

> By dancing meteors then, that ceaseless shake
> A waving blaze refracted o'er the heavens,
> And vivid moons, and stars that keener play
> With double lustre from the glossy waste:
> Ev'n in the depth of Polar Night, they find
> A wond'rous day: enough to light the chase,
> Or guide their daring steps to Finland-fairs.
>
> WINTER, l. 859.

CONVERSATION XXXIX.

Of Mercury.

Tutor. Having fully described the earth and the moon, the former a primary planet, and the latter its attendant satellite, or secondary planet, we shall next consider the other planets in their order, with which, however, we are less interested.

MERCURY, you recollect, is the planet nearest the sun; and Venus is the second in order. These are called inferior planets.

Charles. Why are they thus denominated?

Tutor. Because they both revolve in orbits which are included *within* that of the earth; thus (Plate v. Fig. 2.) Mercury makes his annual journey round the sun in the orbit *a*; Ve-

nus in *b*, and the earth, farther from that luminary than either of them, makes its circuit in *t*.

James. How is this known?

Tutor. By observation; for by attentively watching the progress of these bodies, it is found that they are continually changing their places among the fixed stars, and that they are never seen in opposition to the sun; that is, they are never seen in the western side of the heavens in the morning when he appears in the east; nor in the eastern part of the heavens in the evening when the sun appears in the west.

Charles. Then they may be considered as attendants upon the sun?

Tutor. They may: Mercury is never seen from the earth at a greater distance from the sun, than about twenty-eight degrees, or about as far as the moon appears to be from the sun on the second day after its change; hence it is that we so seldom see him; and when we do, it is for so short a time, and always in twilight, that sufficient observations have not been made to ascertain whether he has a diurnal motion on his axis.

James. Would you then conclude that he has such a motion?

Tutor. I think we ought; because it is known to exist in all those planets upon which observations of sufficient extent have been made, and therefore we may surely infer, without much chance of error, that it belongs also to Mercury,

and the Herschel, the former from its vicinity to the sun, and the latter from its great distance from that body, having at present eluded the investigation of the most indefatigable astronomers.

Charles. At what distance is Mercury from the sun?

Tutor. He revolves round that body at about thirty-seven millions of miles distance, in eighty-eight days nearly; and therefore you can now tell me how many miles he travels in an hour.

James. I can; for supposing his orbit circular, I must multiply the 37 millions by 6,* which will give 222 millions of miles for the length of his orbit; this I shall divide by 88, the number of days he takes in performing his journey, and the quotient resulting from this, must be divided by 24, for the number of hours in a day; and by these operations, I find that Mercury travels at the rate of more than 105,000 miles in an hour.

Charles. How large is Mercury?

Tutor. He is the smallest of all the planets. His diameter is something more than 3200 miles in length.

James. His situation being so much nearer to the sun than ours, he must enjoy a considerably greater share of its heat and light.

Tutor. So much so, as would indeed infalli-

* See p. 160.

bly burn every thing belonging to the earth to atoms, were she similarly situated. The heat of the sun at Mercury, must be seven times greater than our summer heat:

> ———Mercury the first
> Near ordering on the day, with speedy wheel
> Flies swiftest on, inflaming where he comes,
> With *seven-fold* splendour, all the azure road.
>
> MALLET'S EXCURSION.

Charles. And do you imagine that, thus circumstanced, this planet can be inhabited?

Tutor. Not by such beings as we are: you and I could not long exist at the bottom of the sea; yet the sea is the habitation of millions of living creatures; why then may there not be inhabitants in Mercury, fitted for the enjoyment of the situation which that planet is calculated to afford? If there be not, we must be at a loss to know why such a body was formed; certainly it could not be intended for our benefit, for it is rarely even seen by us:

> Ask for what end the heavenly bodies shine?
> Earth for whose use? Pride answers, "'Tis for mine:
> ———suns to light me rise,
> My footstool earth, my canopy the skies."
>
> POPE.

> But do these worlds display their beams, or guide
> Their orbs, to serve thy use, to please thy pride?
> Thyself but dust, thy stature but a span,
> A moment thy duration; foolish man!
> As well may the minutest emmet say,
> That Caucasus was raised to pave his way:
> The snail, that Lebanon's extended wood

Was destined only for his walk and food:
The vilest cockle, gaping on the coast
That rounds the ample seas, as well may boast,
The craggy rock projects above the sky,
That he in safety at its foot may lie;
And the whole ocean's confluent waters swell,
Only to quench his thirst, or move and blanch his shell.

PRIOR.

CONVERSATION XL.

Of Venus.

Tutor. We now proceed to Venus, the second planet in the order of the solar system, but by far the most beautiful of them all:

Fairest of stars, last in the train of night,
If better thou belong not to the dawn,
Sure pledge of day, that crown'st the smiling morn
With thy bright circlet, praise him in thy sphere,
While day arises, that sweet hour of prime.

MILTON.

James. How far is Venus from the sun?

Tutor. That planet is sixty-eight millions of miles from the sun, and she finishes her journey in 224¾ days, consequently she must travel at the rate of 75,000 miles in an hour.

Charles. Venus is larger than Mercury, I dare say?

Tutor. Yes, she is nearly as large as the earth, which she resembles also in other respects,

her diameter being about 7700 miles in length, and she has a rotation about her axis in 23 hours and 20 minutes. The quantity of light and heat which she enjoys from the sun, must be double that which is experienced by the inhabitants of this globe.

James. Is there also a difference in her seasons, as there is here ?

Tutor. Yes, in a much more considerable degree. The axis of Venus inclines about 75 degrees, but that of the earth inclines only 23½ degrees, and as the variety of the seasons in every planet depends on the degree of the inclination of its axis, it is evident that the seasons must vary more with Venus than with us.

Charles. Venus appears to us larger sometimes than at others.

Tutor. She does ; and this, with other particulars, I will explain by means of a figure. Suppose S (Plate VII. Fig 17.) to be the sun, T the earth in her orbit, and *a*, *b*, *c*, *d*, *e*, *f*, Venus in her's : now it is evident that when Venus is at *a*, between the sun and earth, she would, if visible, appear much larger than when she is at *d* in opposition.

James. That is because she is so much nearer in the former case than in the latter, being in the situation *a*, but 27 millions of miles from the earth T, but at *d*, she is 163 millions of miles off.

Tutor. Now as Venus passes from *a*, through *b*, *c*, to *d*, she may be observed by means of a

good telescope, to have all the same phases as the moon has in passing from new to full: therefore when she is at *d* she is full, and is seen among the fixed stars in the beginning of Cancer: during her journey from *d* to *e*, she proceeds with a *direct* motion in her orbit, and at *e* she is seen in Leo, and will appear to an inhabitant of the earth, for a few days to be *stationary*, not seeming to change her place among the fixed stars, for she is coming towards the earth in a direct line: but in passing from *e* to *f*, though still with a direct motion, yet to a spectator at T, her course will seem to be back again, or *retrograde*, for she will seem to have gone back from *x* to *y*; her path will appear retrograde till she gets to *c*, when she will again appear *stationary*, and afterwards from *e* to *d*, and from *d* to *e*, it will be *direct* among the fixed stars.

Charles. When is Venus an evening, and when a morning star?

Tutor. She is an evening star all the while she appears *east* of the sun, and a morning star while she is seen *west* of him:

> Next Venus to the *westward* of the sun
> Full orb'd her face, a golden plain of light
> Circles her larger round. Fair *morning* star
> That leads on dawning day to yonder world
> The *seat of Man.*
>
> MALLET'S EXCURSION.

When she is at *a* she will be invisible, her dark side being towards us, unless she be exactly

in the node, in which case she will pass over the sun's face like a little black spot.

James. Is that called the transit of Venus?

Tutor. It is; and it happens twice only in about one hundred and twenty years. By this phenomenon astronomers have been enabled to ascertain with great accuracy the distance of the earth from the sun; and having obtained this, the distances of the other planets are easily found. By the two transits which happened in 1761, and 1769, it was clearly demonstrated, that the mean distance of the earth from the sun was between ninety-five and ninety-six millions of miles.

Charles. How do you find the distances of the other planets from the sun, by knowing that of the earth?*

Tutor. I will endeavour to make this plain to you. Kepler, a great astronomer, discovered that all the planets are subject to one general law, which is, that the *squares of their periodical times are proportional to the cubes of their distances from the sun.*

James. What do you mean by the *periodical times?*

Tutor. I mean the times which the planets

* The remainder of this conversation may be omitted by those young persons who are not ready in arithmetical operations. The author, however, knows from experience, that children may, at a very early age, be brought to understand these higher parts of arithmetic.

take in revolving round the sun; thus the periodical time of the earth is 365¼ days; that of Venus 224¼ days; that of Mercury 88 days.

Charles. How then would you find the distance of Mercury from the sun?

Tutor. By the rule of three: I would say as the square of 365 days (the time which the earth takes in revolving about the sun) is to the square of 88 days, (the time in which Mercury revolves about the sun,) so is the cube of 95 millions, (the distance in miles of the earth from the sun) to a fourth number.

James. And is that fourth number the distance in miles of Mercury from the sun?

Tutor. No; you must extract the cube root of that number, and then you will have about thirty-seven millions of miles for the answer, which is the true distance at which Mercury revolves about the sun.

CONVERSATION XLI.

Of Mars.

Tutor. Next to Venus is the earth and her satellite the moon; but of these sufficient notice has already been taken, and therefore we shall pass on to the planet Mars, which is known in the heavens by a dusky red appearance. Mars,

together with Jupiter, Saturn, and the Herschel, are called superior planets, because the orbit of the earth is enclosed by their orbits.

Charles. At what distance is Mars from the sun?

Tutor. About 144 millions of miles; the length of his year is equal to 687 of our days, and therefore he travels at the rate of more than 53 thousand miles in an hour; his diurnal rotation on his axis is performed in 24 hours and 39 minutes, which makes his figure that of an oblate spheroid.

James. How is the diurnal motion of this planet discovered?

Tutor. By means of a very large spot which is seen distinctly on his face, when he is in that part of his orbit which is opposite to the sun and earth.

Charles. Is Mars as large as the earth?

Tutor. No; his diameter is only 4189 miles in length, which is but little more than half the length of the earth's diameter. And owing to his distance from the sun he will not enjoy one half of the light and heat which we enjoy.

James. And yet, I believe, he has not the benefit of a moon.

Tutor. No moon has ever been discovered belonging either to Mercury, Venus, or Mars.

Charles. Do the superior planets exhibit similar appearances of direct and retrograde motion to those of the inferior planets?

Tutor. They do: suppose s (Plate VIII. Fig. 18.) the sun: *a, b, c, d, e, f, g, h,* the earth, in different parts of its orbit, and *m* Mars in his orbit. When the earth is at *a*, Mars will appear among the fixed stars at *x*: when by its annual motion the earth has arrived at *b, d,* and *f*, respectively, the planet Mars will appear in the heavens at *y, z,* and *w*: when the earth has advanced to *g*, Mars will appear stationary at *o*: to the earth in its journey from *g* to *h* the planet will seem to go backwards or retrograde in the heavens from *o* to *z*, and this retrograde motion will be apparent till the earth has arrived at *a*, when the planet will again appear stationary.

James. I perceive that Mars is retrograde when in *opposition*, and the same is, I suppose, applicable to the other superior planets; but the retrograde motion of Mercury and Venus is when those planets are in *conjunction*.

Tutor. You are right: and you see the reason, I dare say, why the superior planets may be in the west in the morning when the sun rises in the east, and the reverse.

Charles. For when the earth is at *d*, Mars may be at *n*, in which case the earth is between the sun and the planet: I observe also that the planet Mars, and consequently the other superior planets, are much nearer the earth at one time than at others.

Tutor. The difference with respect to Mars is

no less than 190 millions of miles, the whole length of the orbit of the earth. This will be a proper time to explain what is meant by the *Heliocentric* longitude of the planets referred to in the Ephemeris.

James. Yes, I remember you promised to explain this when you came to speak of the planets; I do not know the meaning of the word heliocentric.

Tutor. It is a term used to express the place of any heavenly body as seen from the sun; whereas the *geocentric* place of a planet, is the position which it has when seen from the earth.

Charles. Will you show us by a figure in what this difference consists?

Tutor. I will: let s (Plate VIII. Fig. 19.) represent the place of the sun, *b* Venus in its orbit, *a* the earth in her's, and *c* Mars in his orbit, and the outermost circle will represent the sphere of fixed stars. Now to a spectator on the earth *a*, Venus will appear among the fixed stars in the beginning of Scorpio, but as viewed from the sun, she will be seen beyond the middle of Leo. Therefore the *Geocentric* longitude of Venus will be in Scorpio, but her *Heliocentric* longitude will be in Leo. Again, to a spectator at *a*, the planet Mars at *c*, will appear among the fixed stars, towards the end of the sign of Pisces; but as viewed from the sun he will be seen at the beginning of the sign Aries; consequently the *geocentric* longitude of Mars is in Pisces; but his *heliocentric* longitude is in Aries.

CONVERSATION XLII.

Of Jupiter.

Tutor. We now come to Jupiter, the largest of all the planets, which is easily known by his peculiar magnitude and brilliancy.

Charles. Is Jupiter larger than Venus?

Tutor. Though he does not appear so large, yet the magnitude of Venus bears but a very small proportion to that of Jupiter, whose diameter is 90,000 miles in length, consequently his bulk will exceed the bulk of Venus 1500 times: his distance from the sun is estimated at more than 490 millions of miles.

James. Then he is *five* times farther from the sun, than the earth, and consequently, as light and heat diminish in the same proportion as the squares of the distances from the illuminating body increase, the inhabitants of Jupiter enjoy but a twenty-fifth part of the light and heat of the sun that we enjoy.

Tutor. Another thing remarkable in this planet is, that it revolves on its axis, which is perpendicular to its orbit, in 10 hours, and in consequence of this swift diurnal rotation, his equatorial diameter is 6000 miles greater than his polar diameter.

Charles. Since then a variety in the seasons of a planet depends upon the inclination of the axis to its orbit, and since the axis of Jupiter has no inclination, there can be no difference in his seasons, nor any in the length of his days and nights.

Tutor. You are right, his days and nights are always five hours each in length; and at his equator, and its neighbourhood, there is perpetual summer; and an everlasting winter in the polar regions.

James. What is the length of his year?

Tutor. It is equal to nearly 12 of ours, for he takes 11 years, 314 days, and 10 hours, to make a revolution round the sun; consequently he travels at the rate of more than 28,000 miles in an hour.

This noble planet is accompanied with four satellites, which revolve about him at different distances, and in different periodical times; the *first* in about 1 day and 11 hours: the *second* in 3 days, 13 hours: the *third* in 7 days, 3 hours: and the *fourth* in 16 days and 16 hours.

> Beyond the sphere of *Mars* in distant skies,
> Revolves the mighty magnitude of *Jove*
> With kingly state, the rival of the sun.
> About him round *four planetary moons*
> On earth with wonder all night long beheld
> Moon above moon, his fair attendants dance.
>
> MALLET'S EXCURSION.

Charles. And are these satellites, like our moon, subject to be eclipsed?

Tutor. They are; and their eclipses are of considerable importance to astronomers, in ascertaining with accuracy the longitude of different places on the earth.

By means of the eclipses of Jupiter's satellites, a method has been also obtained of demonstrating that the motion of light is *progressive*, and not *instantaneous*, as was once supposed. Hence it is found that the velocity of light is nearly 11,000 times greater than the velocity of the earth in its orbit, and more than a million of times greater than that of a ball issuing from a cannon. This discovery is alluded to by the last-mentioned poet: speaking of an observer of the eclipses and Jupiter's satellites, he says:

> By these observ'd the *rapid progress finds*
> Of *light* itself; how swift the headlong ray
> Shoots from the sun's height through unbounded space,
> At once enlight'ning air, and earth, and heaven.

Rays of light come from the sun to the earth in 8 minutes, that is, at the rate of 12 millions of miles in a minute nearly.

CONVERSATION XLIII.

Of Saturn.

Tutor. We are now arrived at Saturn in our descriptions, which, till within these twenty years, was esteemed the most remote planet of the solar system.

Charles. How is he distinguished in the heavens?

Tutor. He shines with a pale dead light, very unlike the brilliant Jupiter, yet his magnitude seems to vie with that of Jupiter himself. The diameter of Saturn is nearly 80,000 miles in length: his distance from the sun is more than 900 millions of miles, and he performs his journey round that luminary in a little less than 30 of our years, consequently he must travel at a rate not much short of 21,000 miles in an hour.

James. His great distance from the sun must render an abode on Saturn extremely cold and dark too, in comparison of what we experience here.

Tutor. His distance from the sun being between 9 and 10 times greater than that of the earth, he must enjoy about 90 times less light and heat; it has nevertheless been calculated that the light of the sun at Saturn is 500 times greater than we enjoy from our *full moon*.

Charles. The day-light at Saturn, then, cannot be very contemptible: I should hardly have thought that the light of the sun here was 500 times greater than that experienced from a full moon.

Tutor. So much greater is our meridian light than this, that during the sun's absence behind a cloud, when the light is much less strong than when we behold him in all his glorious splendour, it is reckoned that our day-light is 90,000 times greater than the light of the moon at its full.

James. But Saturn has several moons I believe?

Tutor. He is attended by *seven* satellites, or moons, whose periodical times differ very much; the one nearest to him performs a revolution round the primary planet in 22 hours and a half; and that which is most remote takes 79 days and 7 hours for his monthly journey: this last satellite is known to turn on its axis, and in its rotation is subject to the same law which our moon obeys, that is, it revolves on its axis in the same time in which it revolves about the planet. Besides the seven moons, Saturn is encompassed with two broad rings which are probably of considerable importance in reflecting the light of the sun to that planet; the breadth of the inner ring is 20,000 miles, that of the outer ring 7200 miles, and the vacant space between the two rings is 2839 miles. These rings give Saturn a very different appearance to any of the other

planets. Plate VIII. Fig. 20, is a representation of Saturn as seen through a good telescope. On the supposition that Saturn was the most remote planet of our system, he is thus described by Mallet in his excursion:

> Last, outmost Saturn walks his frontier round
> The boundary of worlds, with his pale moons,
> Faint glimmering thro' the gloom which night has thrown
> Deep-dyed and dead o'er this chill globe forlorn:
> An endless desert, where extreme of cold
> Eternal sits, as in his native seat,
> On wintery hills of never-thawing ice.
> Such *Saturn's* earth; and even here the sight
> Amid these doleful scenes, new matter finds
> Of wonder and delight! a mighty *ring!*

Charles. Is it known whether Saturn turns on its axis?

Tutor. According to Dr. Herschel, it has a rotation about its axis in 12 hours 13½ minutes: this he computed from the equatorial diameter being longer than the polar diameter in the proportion of 11 to 10. Dr. Herschel has also discovered that the ring, just mentioned, revolves about the planet in 10 hours and a half.

CONVERSATION XLIV.

Of the Herschel Planet.

Tutor. We have but one more planet to describe, that is the Herschel.

James. Was it discovered by Dr. Herschel?

Tutor. It was, on the 13th of March, 1781, and therefore by astronomers in general it is denominated the Herschel planet; though by the Doctor himself it was named the Georgium Sidus, or Georgian star, in honour of his present majesty George the Third, who has for many years been a liberal patron to this great and most indefatigable astronomer.

Charles. I do not think that I have ever seen this planet.

Tutor. Its apparent diameter is too small to be discerned readily by the naked eye, but it may be easily discovered in a clear night, when it is above the horizon, by means of a good telescope, its situation being previously known from the Ephemeris.

James. Is it owing to the smallness of this planet, or to its great distance from the sun, that we cannot see it with the naked eye?

Tutor. Both these causes are combined: in comparison of Jupiter and Saturn it is small, his diameter being less than 35,000 miles in length;

and his distance from the sun is estimated at more than one thousand eight hundred millions of miles from that luminary, around which, however, he performs his journey in eighty-two of our years, consequently he must travel at the rate of 16,000 miles an hour.

Charles. But if this planet has been discovered only twenty-two years, how is it known that it will complete its revolution in eighty-two years?

Tutor. By a long series of observations it was found to move with such a velocity, as would carry it round the heavens in that period. Moreover, when it was first discovered, it was in Gemini, and in August, 1803, it had advanced in the 11° of Libra, more than a fourth part of its journey; and now in June, 1809, it is in the eighth of Scorpio.

James. How many moons has the Herschel?

Tutor. He is attended by six satellites or moons, of which, the one nearest to the planet performs his revolution round the primary in five days and twenty-three hours, but that which is the most remote from him takes 107 days and 16 hours for his journey.

Charles. Is there any idea formed as to the light and heat enjoyed by this planet?

Tutor. His distance from the sun is nineteen times greater than that of the earth, consequently since the square of 19 is 361, the light and heat experienced by the inhabitants of that planet

must be 361 times less than *we* derive from the rays of the sun.

The proportion of light enjoyed by the Herschel has been estimated at about equal to the effect of two hundred and forty-nine of our full moons.

CONVERSATION XLV.

Of Comets.

Tutor. Besides the seven primary planets, and the eighteen secondary ones or satellites, which we have been describing, there are other bodies belonging to the solar system, called comets, to which Thomson, in his Summer, beautifully alludes:

——————Amid the radiant orbs
That more than deck, that animate the sky,
The life-infusing suns of other worlds;
Lo! from the dread immensity of space
Returning with accelerated course
The rushing *comet* to the sun descends,
And as he sinks below the shading earth,
With awful train projected o'er the heavens,
The guilty nations tremble.

SUMMER, line 1702.

Charles. Do comets resemble the planets in any respects?

Tutor. Like them they are supposed to revolve about the sun in elliptical orbits, and to describe equal areas in equal times; but they do not appear to be adapted for the habitation of animated beings, owing to the great degrees of heat and cold to which, in their course, they must be subjected.

The comet seen by Sir Isaac Newton, in the year 1680, was observed to approach so near the sun, that its heat was estimated by that great man, to be 2000 times greater than that of red-hot iron.

James. It must have been a very solid body to have endured such a heat without being entirely dissipated.

Tutor. So indeed it should seem; and a body thus heated must retain its heat a long time; for a red-hot globe of iron, of a single inch in diameter, exposed to the open air, will scarcely lose all its heat in an hour; and it is said, that a globe of red-hot iron, as large as our earth, would scarcely cool in 50,000 years. See Enfield's Institutes of Natural Philosophy, p. 296, second edition.

Charles. Are the periodical times of the comets known?

Tutor. Not with any degree of certainty; it was supposed that the periods of three of them had been distinctly ascertained. The *first* of

these appeared in the years 1531, 1607, and 1682, and it was expected to return every 75th year; and one which, as had been predicted by Dr. Halley, appeared in 1758, which was supposed to be the same.

The *second* of them appeared in 1532, and 1661, and it was expected that it would again make its appearance in 1789, but in this the astronomers of the present day have been disappointed.

The *third* was that which appeared in 1680, and its period being estimated at 575 years cannot, upon that supposition, return until the year 2255. This last comet at its *greatest* distance is eleven thousand two hundred millions of miles from the sun, and its *least* distance from the sun's centre was but four hundred and ninety thousand miles; in this part of its orbit it travelled at the rate of eight hundred and eighty thousand miles in an hour.

James. Do all bodies move faster or slower in proportion as they are nearer to, or more distant from their centre of motion?

Tutor. They do, for if you look back upon the last six or seven lectures, you will see that the Herschel, which is the most remote planet in the solar system, travels at the rate of 16,000 miles an hour: Saturn, the next nearer in the order, 21,000 miles; Jupiter 28,000 miles; Mars 53,000 miles; the earth 65,000 miles; Venus 75,000 miles; and Mercury at the rate of 105,000 miles in an hour. But here we come

to a comet whose progressive motion in that part of its orbit which is nearest to the sun, is more than equal to eight times the velocity of Mercury.

Charles. Were not comets formerly dreaded, as awful prodigies intended to alarm the world?

Tutor. Comets are frequently accompanied with a luminous train called the tail, which is supposed to be nothing more than vapour rising from the body in a line opposite to the sun, but which, to uninformed people, has been a source of terror and dismay, and to this opinion many of our poets have alluded:

——————Where the *train*
Of comets wander in eccentric ways
With infinite excursion through th' immense
Of ether, traversing from sky to sky
Ten thousand regions, in their winding road,
Whose length to trace imagination fails;
Various their paths——————
While distant orbs with wonder and amaze
Mark their approach, and night by night alarm'd
Their dreaded progress watch, as of a foe
Whose march is ever fatal, in whose train
Famine and war, and desolating plague,
Each on his pale horse rides, the ministers
Of angry Heaven to scourge offending worlds.

MALLET'S EXCURSION.

CONVERSATION XLVI.

Of the Sun.

Tutor. Having given you a particular description of the planets which revolve about the sun, and also of the satellites which travel round the primary planets as central bodies, while they are carried at the same time with these bodies round the sun, we shall conclude our account of the solar system by taking some notice of the sun himself:

> Informer of the planetary train,
> Without whose quick'ning glance their cumbrous orbs
> Were brute unlovely mass, inert and dead,
> And not, as now, the green abodes of life.
>
> Thomson's Autumn, line 1086.

James. You told us a few days ago, that the sun has a rotation on its axis; how is that known?

Tutor. By the spots on its surface, it is known that he completes a revolution from west to east on his axis in about twenty-five days, two days less than his *apparent* revolution, in consequence of the earth's motion in her orbit, in the same direction.

Charles. Is the figure of the sun globular?

Tutor. No; the motion about its axis renders it spheroidical, having its diameter at the equator longer than that which passes through the poles.

The sun's diameter is equal to 100 diameters of the earth, and therefore his bulk must be a million of times greater than that of the earth, but the density of the matter of which it is composed is four times less than the density of our globe.

We have already seen that by the attraction of the sun, the planets are retained in their orbits, and that to him they are indebted for light, heat, and motion:

> Fairest of beings! first created light!
> Prime cause of beauty! for from thee alone
> The sparkling gem, the vegetable race,
> The nobler worlds that live and breathe their charms,
> The lovely hues peculiar to each tribe,
> From thy unfailing source of splendour draw!
> In thy pure shine, with transport I survey
> This firmament, and these her rolling worlds
> Their magnitudes and motions.
>
> MALLET'S EXCURSION.

CONVERSATION XLVII.

Of the Fixed Stars.

Tutor. We will now put an end to our astronomical conversations, by referring again to the fixed stars, which, like our sun, shine by their own light.

Charles. Is it then certain that the fixed stars are of themselves luminous bodies; and that the planets borrow their light from the sun?

Tutor. By the help of telescopes it is known that Mercury, Venus, and Mars shine by a borrowed light, for like the moon, they are observed to have different phases according as they are differently situated with regard to the sun. The immense distances of Jupiter, Saturn, and the Herschel planet, do not allow the difference between the perfect and imperfect illumination of their discs or phases to be perceptible.

Now the distance of the fixed stars from the earth is so great, that reflected light would be much too weak ever to reach the eye of an observer here.

James. Is this distance ascertained with any degree of precision.

Tutor. It is not: but it is known with certainty to be so great, that the whole length of the

earth's orbit, viz. 190 millions of miles, is but a point in comparison of it; and hence it is inferred that the distance of the nearest fixed star, cannot be less than a hundred thousand times the length of the earth's orbit;* that is a hundred thousand times 190 millions of miles, or 19,000,000,000,000 miles; this distance being immensely great, the best method of forming some clear conception of it, is to compare it with the velocity of some moving body, by which it may be measured. The swiftest motion with which we are acquainted is that of light, which, as we have seen, is at the rate of twelve millions of miles in a minute; and yet light would be about three years in passing from the nearest fixed star to the earth.

A cannon ball which may be made to move at the rate of twenty miles in a minute, would be 1800 thousand years in traversing the distance. Sound, the velocity of which is thirteen miles in a minute, would be more than two million seven hundred thousand years in passing from the star to the earth. So that if it were possible for the inhabitants of the earth to see the light;—to hear the sound;—and to receive the ball of a cannon discharged at the nearest fixed star; they would not perceive the light of its explosion for three years after it had been fired; nor receive the ball till 1800 thousand years had

* See Dr. Enfield's Institutes of Natural Philosophy, p. 347. Second edition, 1799.

elapsed; nor hear the report for two millions and seven hundred thousand years after the explosion.

Charles. Are the fixed stars at different distances from the earth?

Tutor. Their magnitudes, as you know, appear to be different from one another, which difference may arise either from a diversity in their real magnitudes, or in their distances, or from both these causes acting conjointly. It is the opinion of Dr. Herschel that the different apparent magnitudes of the stars arise from the different distances at which they are situated, and therefore he concludes that stars of the seventh magnitude are at seven times the distance from us that those of the first magnitude are.

By the assistance of his telescopes he is able to discover stars at 497 times the distance of *Sirius* the Dog-Star; from which he infers that with more powerful instruments he should be able to discover stars at still greater distances.

James. I recollect that you told us once, that it had been supposed by some astronomers, that there might be fixed stars at so great a distance from us, that the rays of their light had not yet reached the earth, though they had been travelling at the rate of twelve millions of miles in a minute, from the first creation to the present time.

Tutor. I did; it was one of the sublime speculations of the celebrated Huygens. Dr. Hal-

ley has also advanced, what he says seems to be a metaphysical paradox, viz. that the number of fixed stars must be more than finite, and some of them at a greater than a finite distance from others; and Mr. Addison has justly observed, that this thought is far from being extravagant, when we consider that the universe is the work of infinite power, promoted by infinite goodness, and having an infinite space to exert itself in; so that our imagination can set no bounds to it.

> How distant some of the nocturnal suns!
> So distant, says the sage, 'twere not absurd
> To doubt, if beams set out at Nature's birth,
> Are yet arriv'd at this so foreign world;
> Though nothing half so rapid as their flight.
>
> YOUNG.

Charles. What can be the use of these fixed stars?—not to enlighten the earth, for a single additional moon would give us much more light than them all, especially if it were so contrived as to afford us its assistance at those intervals when our present moon is below the horizon.

Tutor. You are right: they could not have been created for our use, since thousands, and even millions, are never seen but by the assistance of glasses, to which but few of our race have access. Your minds indeed are too enlightened to imagine, like children unaccustomed to reflection, that all things were created for the enjoyment of man. The earth on which we live

is but one of seven primary planets circulating perpetually round the sun as a centre, and with these are connected eighteen secondary planets or moons, all of which are probably teeming with living beings, capable, though in different ways, of enjoying the bounties of the great First Cause.

The fixed stars then are probably suns, which, like our sun, serve to enlighten, warm, and sustain other systems of planets and their dependent satellites.

James. Would our sun appear as a fixed star at any great distance?

Tutor. It certainly would: and Dr. Herschel thinks there is no doubt, but that it is one of the heavenly bodies belonging to that tract of the heavens known by the name of the *Milky Way.*

Charles. I know the milky way in the heavens, but I little thought that I had any concern with it otherwise than as an observer.

Tutor. The milky way consists of fixed stars, too small to be discerned with the naked eye; and if our sun be one of them, the earth and other planets are closely connected with this part of the heavens.

But, Gentlemen, it is time that we take our leave of this subject for the present. For your attention to those instructions, which, on this and other topics, I have been able to communicate, accept my best thanks. For your future welfare and happiness, my heart is deeply interested. You will not, I flatter myself, very

soon forget that connexion which has subsisted between us for a long course of years. From my mind the remembrance of your kindness can never be obliterated. Permit, me, then, as a testimony of my gratitude and sincere affection, to recommend to your future attention the works of nature and creation, by a careful investigation of which you will necessarily be led to the contemplation and love of the God of Nature.

Your knowledge, young as you yet are, of the fundamental principles of Geometry and Algebra, is such as to render scientific pursuits easy and pleasant. And your understandings are not more capable of entering into the sublime speculations of science, than your hearts are adapted to receive and cherish those impressions of gratitude, which are the natural consequences of enlarged and comprehensive views of the being and perfections of the Deity. In all your studies and pursuits, then, never forget, that

——————you cannot go
Where Universal Love not smiles around,
Sustaining all yon orbs, and all their suns;
From seeming evil still educing good,
And better thence again, and better still,
In infinite progression.

Thomson.

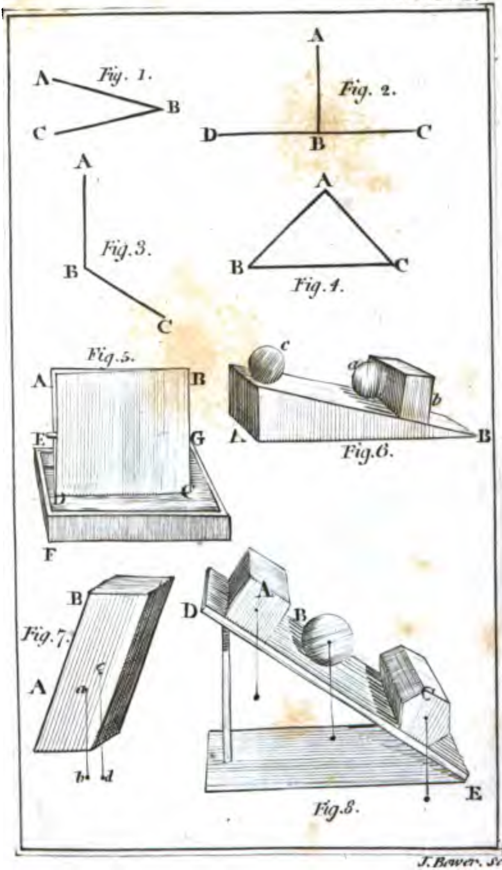
END OF VOLUME I.

CONTENTS OF VOL. I.

MECHANICS.

ASTRONOMY.

CONTENTS.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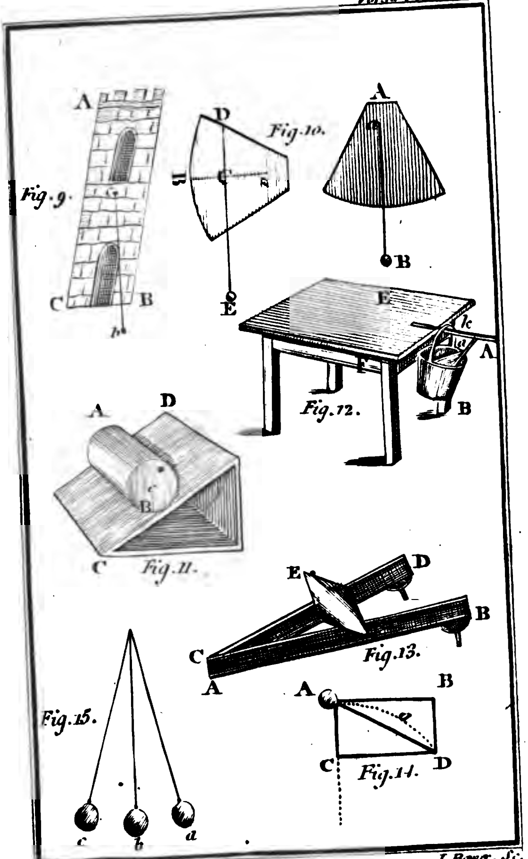
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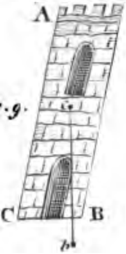
Fig. 9.



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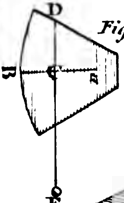

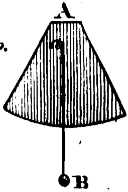

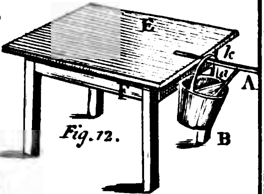

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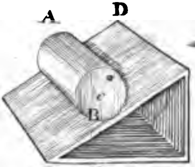

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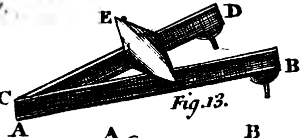
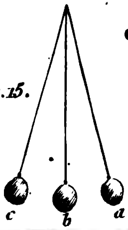


Fig. 13.

Fig. 15.



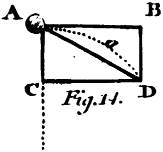


Fig. 14.

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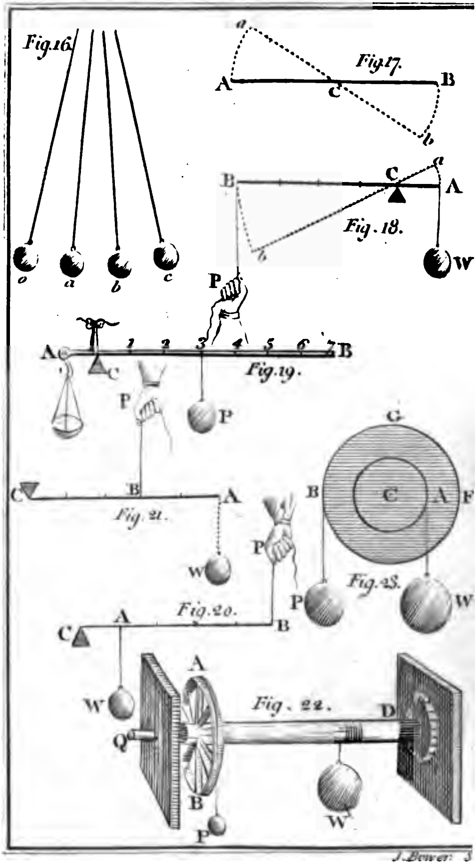
Fig.16.
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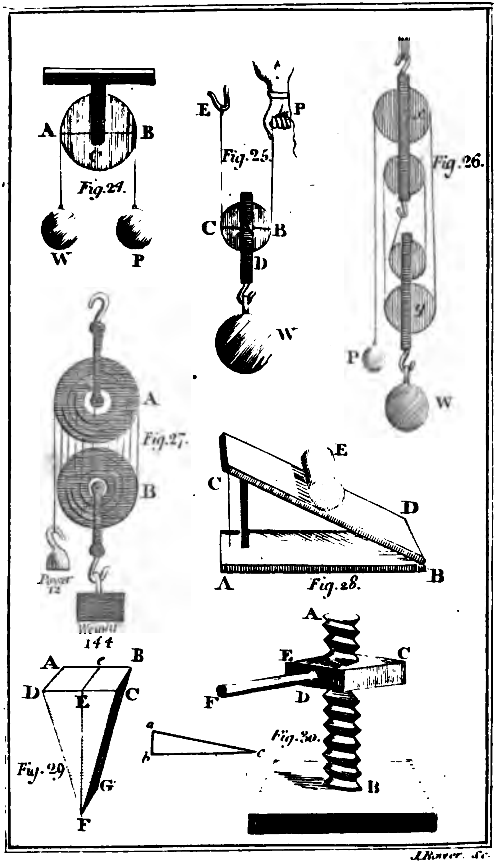
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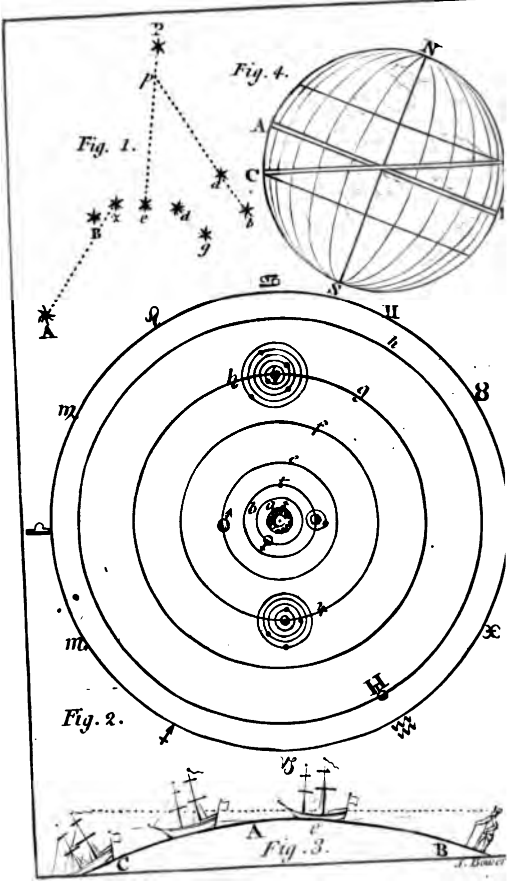
Fig. 1.
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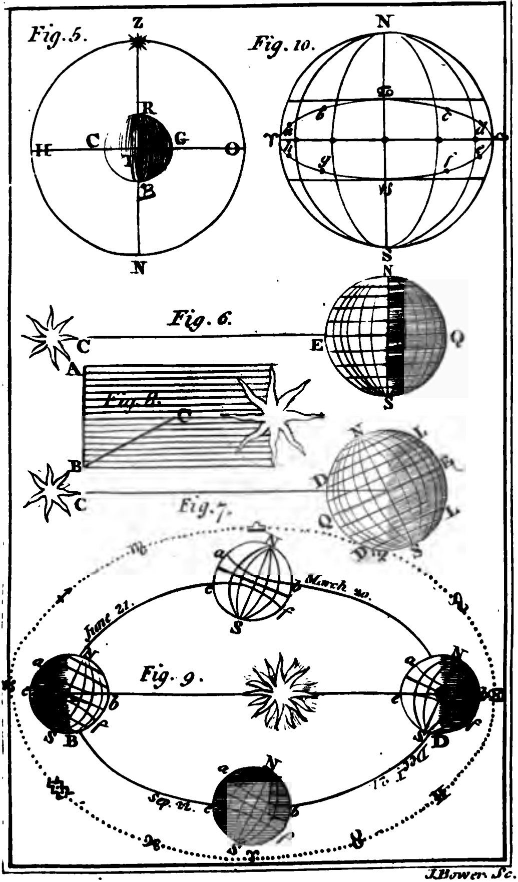
J. Bower



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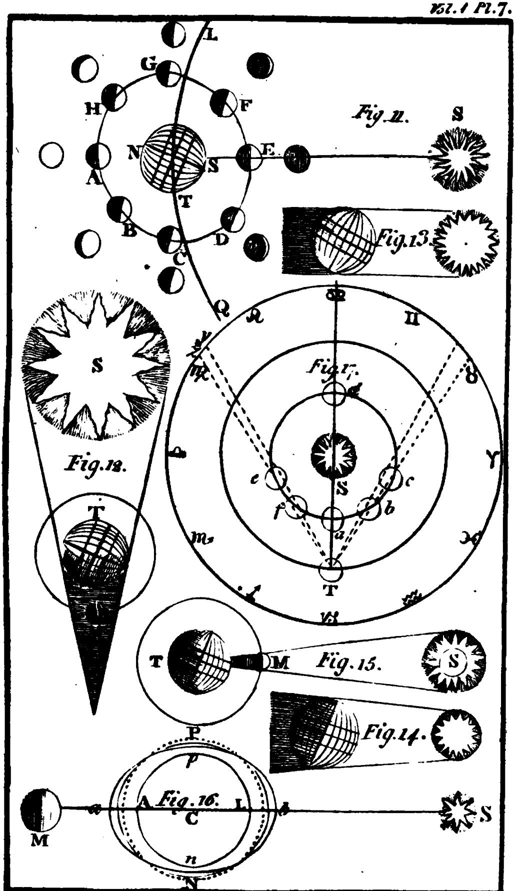

Fig. 11.
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Fig. 13.
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Fig. 15.
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Fig. 14.
Fig. 16.
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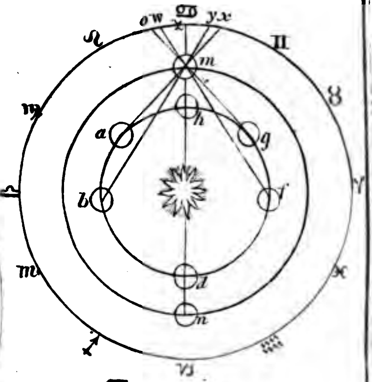

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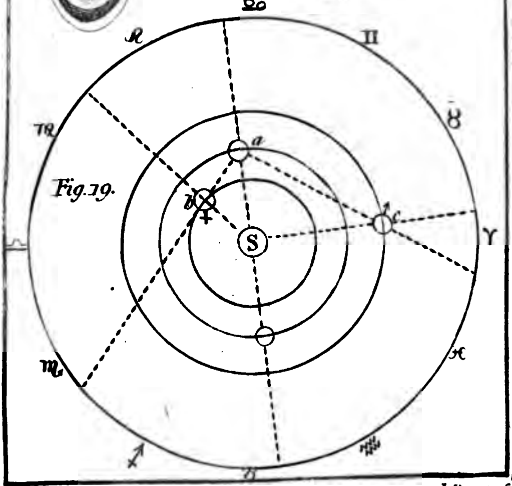

Fig. 19.

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